Electric Guitar Amplifier Handbook

by

Jack Darr

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VISIT…

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Preface

The guitar is a universally popular musical instrument. The use of electronic amplification isn't confined to guitars alone, but is used on many instruments in the band. Unamplified string instruments do not have a great deal of sound output, but with the super-powered amplifiers used today, one guitar can have a sound output greater than a whole old-fashioned brass band.

These musical instrument amplifiers are used everywhere, in cities, towns, and hamlets. The service and maintenance of these amplifiers can provide a good part of an electronics technician's business. These amplifiers contain many "special effects" circuits, such as reverberation, vibrato/tremolo, "fuzz," percussion, and others. However, the heart of every musical instrument amplifier is a plain old audio amplifier, which can be tested and repaired with standard electronic test equipment already on hand in the average service shop.

For the instrument owners who have a good grasp of the fundamentals of electronics, this book will provide the basic information you need to make repairs properly and safely. We'll give you tests to make servicing and troubleshooting much easier, on both tube and transistor amplifiers of all sizes. You can check power output, distortion, and sensitivity, and keep the instrument in perfect working order with a minimum of trouble.

In the past, due to the specialized nature of this field, it has been hard to get service data and information on these instruments. This book has been designed to give you the basic "typical circuits" used in all of these amplifiers. In addition, you'll find schematic diagrams of a great many amplifiers, including the most popular makes, from the small practice amplifiers to the "big boomers" with enough power to fill a football stadium.

Transistor amplifiers, especially the super-power 200 to 300-watt types, require special techniques to service them safely. You'll find an expanded section on these in this edition, as well as a complete listing of all of the "safety precautions" which must be taken when servicing a transistor amplifier. You'll also find data on how to choose a suitable replacement-type transistor for an unknown type. There are a great many types of transistors; however, with this method, you'll be able to use "stock" replacements safely for practically 100% of them.

All of the test and servicing methods mentioned in this book have been "bench-tested;" they were developed by working on actual commercial amplifiers. The power-output tests were taken from official factory service data from the many manufacturers who helped me to prepare this book.

The author wishes to acknowledge the following manufacturers for their cooperation in supplying many of the schematics used in this book: Allied Radio Shack; Ampeg; Chicago Musical Instrument Co.; Ediphone, Inc.; Electro-Voice, Inc.; Estey Company; Fender Electronic Instrument Company; Gibson, Inc.; Kay Musical Instrument Company; Montgomery Ward & Co.; Sears, Roebuck & Co.; Supro; The Harmony Co.; and Valco.

JACK DARR

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SECTION I

How Guitar Amplifiers Work

Chapter 1

Amplifying the Signal

Technically speaking, the title of this book should be "Servicing Electronically Amplified Musical Instruments" since electric guitars are not the only ones involved. Every instrument in the band can have its own pickup—violins, banjos, string basses, etc. However, there is no question that the guitar is the most popular of the group. Keep in mind that everything in this book can be applied to any of the instruments where electronic amplification has been used. So far, drums have been exempt, but anything can happen.

GENERAL DESCRIPTION

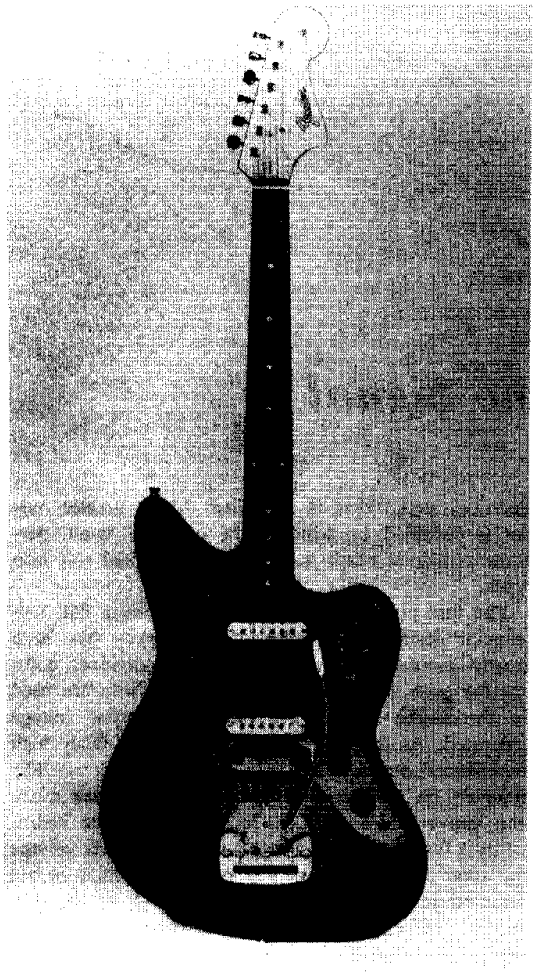
The first electric guitars used contact microphones. These small special microphones, when fastened to the body or shell of an instrument, pick up the actual sound vibrations and convert them into an electrical signal for amplification. They are like a phonograph pickup which changes mechanical vibration into electrical signals. One of the disadvantages is their poor sensitivity. If the amplifier is turned up high enough to get an adequate output, the whole body of the guitar acts as a microphone. When someone speaks toward the instrument or the player shifts it against his clothing, the sound can be heard everywhere. Also, when the sound from the speakers gets into the microphone, acoustic feedback occurs. A different method of picking up the music is obviously needed.

Since all guitars of this type use metal strings, a magnetic pickup has been developed. High impedance coils are wound on iron cores and placed under the strings at a point where the motion of the string is greatest—near the hole of the instrument. Movement of the metal string through the magnetic field of the coil induces a voltage in the coil; this is the electrical signal that is amplified. Much greater output is obtained by winding the coils on small, permanent magnet cores instead of the original soft iron types.

The first pickups used one large coil on a flat, rectangular form. The output of the pickup has been greatly increased by winding small individual coils, one for each string. Many turns of fine wire are used on these—the more wire, the more output voltage generated. As a result, all pickups have a fairly high impedance output. A volume control is usually mounted on the body of the guitar where the musician can reach it quickly. In more elaborate instruments a tone control is also placed here. Other volume and tone controls are located on the amplifier or are mounted in a special foot-pedal housing so the performer can change the volume without taking his fingers off the string.

The first electric guitars were standard instruments with electronic pickups added. Since the acoustic resonance of the guitar body isn't necessary if an electronic pickup is used, special, entirely electric guitars are now built (Fig. 1-1). The body is made of solid wood about 1.5 inches thick. The neck, frets, and proportions are the same as before, of course.

There are two basic types of guitar: the Spanish, which has raised frets on the neck, and the Hawaiian or steel guitar, which has no raised frets. They are played with the fingertips or a pick, by plucking one string at a time or by strumming chords. A steel bar is moved up and down the neck of the Hawaiian guitar to control the pitch, giving the music a characteristic glissando effect. Some special types of guitars have two full sets of strings, each with its own pickup and control (Fig. 1-2). These are built in a rectangu-



Courtesy Fender Electric Instrument Company

Fig. 1-1. An electric guitar.

lar box-shaped case mounted on four legs. The musician sits down to play these, just as he would to play a piano.

The more elaborate instruments have special effects, such as vibrato, tremolo, and echo. These will be discussed in detail in the following chapter. Tone controls of all kinds are used. Most are simple bass-cut or treble-cut types, but some use complex feedback circuits.

THE AMPLIFIER

An electric guitar amplifier is the same as a public address (pa) system. It consists of a source of signal (the microphone or pickup), the amplifier (to build up the weak electrical signal to whatever power is needed), and the speakers. Fig. 1-3 shows a block diagram of such a system.

The amplifiers used are all conventional, meaning that they are practically identical to those used in all kinds of sound equipment. In other words, these amplifiers are basically the same as those used in pa systems, hi-fi record-playing systems, and many others. This similarity makes things easier for the owner and the service technician, too. When they learn the basic circuits, they can apply what they have learned to all guitars. All amplifiers have the same basic divisions; the only difference is in the number of stages used and the total power output of the system.

What does the amplifier do? The signal, which is the electrical equivalent of the musical tone from the guitar, is fed to the input of the amplifier through a shielded cable, to keep it from picking up hum and noise on the way. There it is amplified (raised to a much higher electrical level) to drive the speakers.

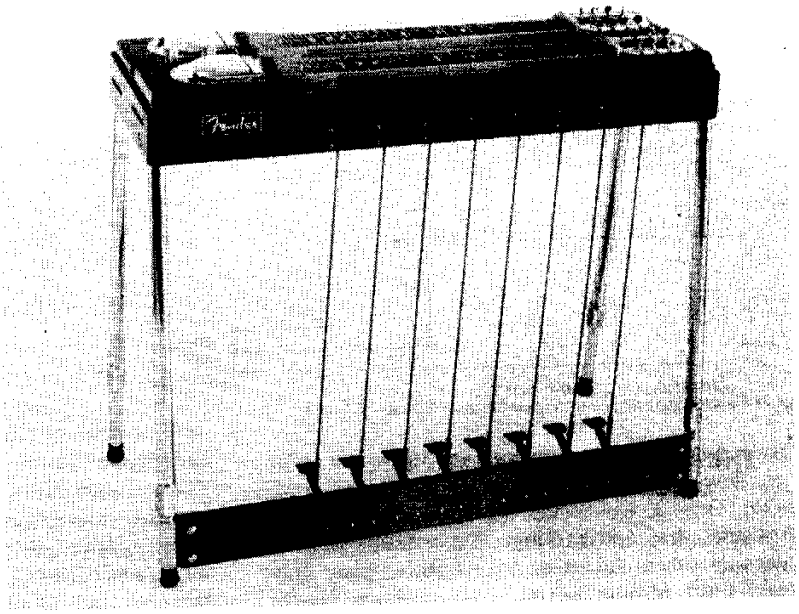
There are two kinds of stages in all amplifiers—transistor types and those with vacuum tubes. The first stages are all voltage amplifiers; they build up the signal voltage so that it is big enough to drive the power output stage to full output. The power-output stage—output for short—is always the last stage in an amplifier—just before the speakers.

Fig. 1-4 shows a block diagram of a typical amplifier. Since all amplifiers use a similar pattern, you should remember it. The only difference will be in the total number of stages and in the special effects added along the way. As you can see in the dotted boxes, tone controls of any kind—tremolo, vibrato, and echo effects—can be added to the signal before it goes to the power-output stage and the speakers. These special effects are discussed in detail in the following pages, and instructions are given so you can add them to amplifiers that do not already have them.

THROUGH THE AMPLIFIER, A STEP AT A TIME

In order to see what each stage does, examine the amplifiers, a step at a time. Begin with the power output stage, just as an engineer would if he were designing the amplifier, since this is the stage that determines how much power output the amplifier is going to have.

Fig. 1-5 shows a typical single-ended output stage —the kind you will find in the smaller amplifiers. The tube used here can be a 6V6, 6L6, 6AQ5, 6BQ5, or any beam-power pentode type. In this circuit maximum power output is about 4 to 6 watts, depending



Courtesy Fender Electric Instrument Company

Fig. 1-2. A pedal guitar.

on the tube type used and the voltage fed from the power supply.

These are called power-amplifier stages, because they must do actual work—move the speaker cone to make the sound. Consequently, the power-amplifier stages have to handle high plate currents as well as voltage. Voltage times current equals power, or work done.

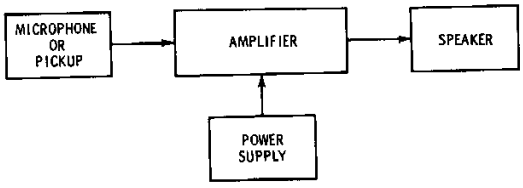


Fig. 1-3. Block diagram of a typical guitar assembly.

To get more power than a single tube can handle and to increase the efficiency of operation, two identical tubes are used in a push-pull circuit. Fig. 1-6 shows this circuit. The object of the game is to get the most current to flow in the output transformer primary, so another tube is hooked up to the other end of it. While the top tube is pushing current downward through the winding, the lower tube is pulling—push-pull. A more technical explanation is that the two tubes are fed signal voltages so that their grids are 180° out of phase, or exactly opposite, one goes up while the other goes down. Because the plates follow the grids, plate current rises in one tube and falls in the other at the same time.

By using a push-pull output circuit, more than double the power output of one tube is obtained. This is due to the increased efficiency of the circuit and the fact that the plate current of both tubes flows through the same primary winding.

TRANSISTOR POWER AMPLIFIERS

If you are used to tube power amplifiers, transistor power-output stages may appear strange. For one thing, most of them do not use output transformers to match the high impedance of the tube plates to the lower impedance of the speaker voice coils. Power transistors are basically low-voltage–high-current devices; therefore, they have very low impedance. This allows them to be connected directly to the speakers, without the use of a large expensive output transformer. This type of circuit is called an "output transformerless" (OTL) circuit, for that reason.

Transformers are used in some of the smaller amplifiers and in certain applications for the higher-powered types. However, most transistor amplifiers use the OTL circuit for its simplicity, lower cost, and efficiency. Although this transistor stage appears different, both physically and schematically, it does exactly the same thing that the tube stage does—it raises the power output (voltage times current) to get the needed amount of power into the speakers.

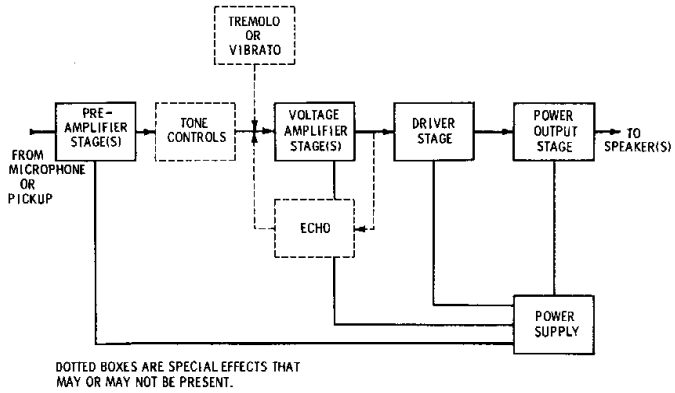


Fig. 1-4. Block diagram of a typical guitar amplifier.

THE OUTPUT TRANSFORMERLESS CIRCUIT—HOW IT WORKS

Transistors accomplish things that are not possible with vacuum tubes. All tubes have positive plate voltages and must have a positive-going voltage on the grid to make the plate current increase. Transistors come in two opposite polarities, npn and pnp. The middle letter in each denotes the polarity of the base element, the control equivalent to the grid of a tube.

In an npn transistor, the base is of a positive material. A positive-going voltage applied to this element makes the collector current increase. However, in a pnp transistor the base is negative, and a negative-going voltage must be applied to increase the collector current. In both types, a bias voltage of the same polarity as the base makes collector current increase; this is called "forward bias." Bias voltage of opposite polarity cuts a transistor off similar to the action of a high negative grid voltage on a tube.

This peculiarity of transistors makes it possible to very readily design push-pull stages of all kinds. Fig. 1-7 shows a basic circuit. Transistors of opposite polarity are used; Q1 is an npn, and Q2 is a pnp. These transistors are exactly alike in characteristics; only the polarity is different.

From the driver stage, a complete ac sine-wave signal is fed simultaneously to the bases of both transistors. During the positive half-cycle (A), Q1 is forward-biased and conducts, while Q2 is reverse-biased and is cut off. Q1 conducts heavily; current flows from the power supply through Q1. Q2 is reverse-biased, and is cut off; it is in effect an open circuit. So, the half-cycle of current flows into the large capacitor C. By normal capacitor-charge action this causes a duplicate pulse to flow through the speaker voice coil to ground.

On the negative half-cycle of the input sine wave (B), Q1 is cut off. Q2 base is forward-biased, and so it conducts, discharging capacitor C and drawing another pulse of current through the speaker to complete the original sine-wave signal. Since this current

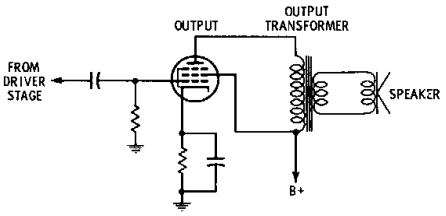


Fig. 1-5. Schematic of a single-ended power-output stage.

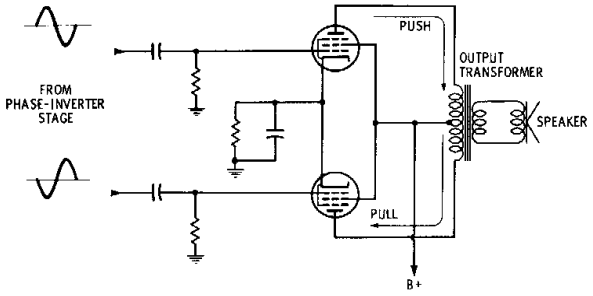


Fig. 1-6. Two-tube push-pull stage.

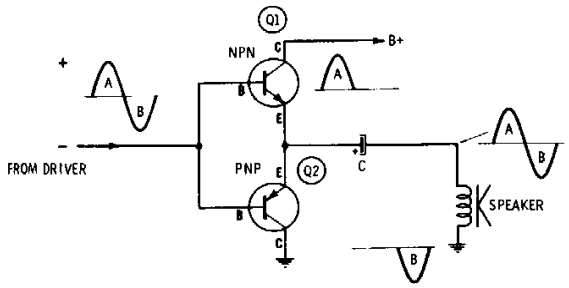


Fig. 1-7. Complementary-symmetry OTL transistor output stage.

flows in the opposite direction to that of the first half-cycle, we have a true ac in the speaker.

If you're wondering where Q2 gets its voltage supply with Q1 between it and the power source and firmly cut off (open circuit), this comes from the big capacitor C. This capacitor was charged during the first half-cycle by current drawn from the power supply through Q1. When Q1 is cut off by the input signal, the capacitor discharges through Q2, and the cycle is complete. Incidentally, this is a highly efficient circuit, due to this action. Note that power is not taken from the power supply during both half-cycles, but only during the *first* half-cycle, when it is used to draw current through the speaker and charge capacitor C. No power is taken from the supply at all during the second half-cycle—we use the same power over again in the opposite direction. So, it is theoretically possible for a Class-B circuit like this to have double the efficiency of a similar tube circuit.

Because the two transistors are just alike but of opposite polarity, this circuit is called a complementary-symmetry output circuit, or "comp-symm" for short.

THE QUASI-COMPLEMENTARY-SYMMETRY OUTPUT CIRCUIT

There is a variation of the complementary-symmetry circuit which uses the same polarity output transistors. This circuit is called a *quasi-complementary-symmetry* (almost complementary-symmetry) output circuit. The necessary phase inversion is done by using opposite-polarity transistors in the driver stages. From input to output, the overall action of this circuit is the same as in the complementary-symmetry circuit. Each output transistor conducts on one half-cycle of the input signal. Fig. 1-8 shows the basic circuit.

The drivers (inverters) are directly connected to the bases of the output pair. Q1 is connected as an emitter-follower, comparable to a cathode-follower in

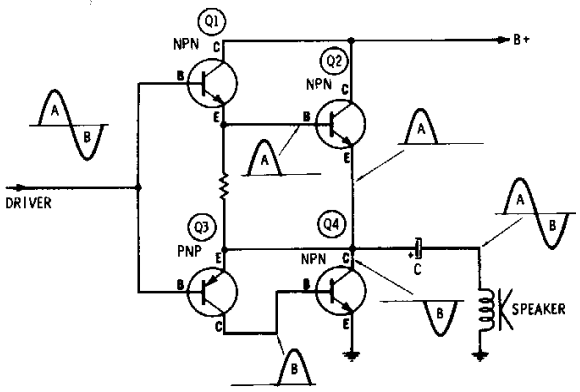


Fig. 1-8. Quasi-complementary-symmetry output stage.

tube circuitry. In transistor circuits, this stage can have current gain, but has little if any voltage gain. Most important of all, the signal is not inverted in polarity. The output signal on the emitter is in phase with the base signal; therefore, with the same polarity, a positive going half-cycle on the base of Q1 appears on the base of Q2. This makes Q2 conduct. The action is exactly the same as before; C is charged, and a half-cycle of current flows through the speaker.

Q3 is a pnp transistor. During the positive half-cycle of the input signal, it is reverse-biased and cut off. This is actually connected as a common emitter; the output is taken off at the collector and is *inverted* in polarity. The negative half-cycle of the signal appears on the base of Q4 as a positive-going signal, making Q4 go into conduction. From here on, the action is exactly the same as before; the top transistor is cut off, so Q4 takes the power from the charge in capacitor C, and the other half-cycle of signal flows through the speaker.

TRANSFORMER-COUPLED CIRCUITS

Fig. 1-9 shows a circuit using an input or driver transformer instead of the phase-inverter transistors. This circuit is not as common as the transformerless type, but it is found in quite a few amplifiers. The only difference is in the use of a driver transformer.

The driver transformer *must* have two separate secondary windings. Since the output transistors are identical, signal pulses of the same polarity are needed to turn them on. The transformer passes the positive going half-cycle through the upper secondary winding without inverting it, to make Q2 conduct. The lower secondary winding inverts the negative half-cycle of the signal resulting in a positive pulse on the base of Q3, causing it to conduct. Aside from this, the action is just the same as before. This type of out-

put stage, using identical transistors, is commonly called a "stacked" circuit—two transistors of the same polarity simply stacked on top of each other.

POWER SUPPLY FOR TRANSISTOR CIRCUITS

There are two types of power supply used in these circuits. The simplest and least expensive one will be by far the most common. This is the one shown in the three preceding output circuits. Voltages will run from about 15 volts up to 45-60 or even 75-100 volts in the bigger amplifiers. One side is ground or common, the other side is hot.

The polarity of the power supply voltage depends on the type of transistor used. In the circuit of Fig. 1-9, for example, pnp transistors are used. The collector of any transistor in an amplifier stage is reverse-biased. With pnp transistors the power supply would be negative to ground. It is quite possible to build this circuit with npn transistors. There will be absolutely no difference in circuit actions, but the polarity of the dc power supply will be positive. Also, the instantaneous polarity of the signal voltage will be reversed. Other than this, there is no difference at all.

Some definitions at this point are in order—common terms that are needed for reference in the test and servicing sections. In the output circuit, the first transistor to go into conduction is called the "top" transistor. This is the one which is connected to the dc power supply in the single-polarity circuits. The one nearest ground or having one element grounded will be the "bottom" transistor. Incidentally, these connections can be reversed, too. You may find a circuit with the emitter of the bottom transistor grounded, as in Fig. 1-9, or with the collector grounded, as in Fig. 1-7. This makes absolutely no difference to the action of the circuit: it is just the same in all types.

THE OUTPUT STAGE AND THE POWER SUPPLY

Since the output stage uses at least 95% of the total power drain of any amplifier, it determines the size and current rating of the dc power supply. Voltages will vary quite a bit, due to the type of tubes or transistors used, but the total "voltage times current" rating of the power supply must be equal to the total of the audio power rating of the amplifier plus the efficiency rating. An amplifier with a 50-watt audio output and a 50% efficiency would need a power supply with a total rating of 75 watts, and so on.

Power supply problems are in the majority, as far as total troubles are concerned; these will be discussed in a separate section.

TUBE-TYPE DRIVER STAGE

A single-ended output stage needs a voltage-amplifier stage capable of delivering enough grid signal to the power stage to drive it to full output. For instance, a single 6V6 tube needs an input signal of about 25 volts peak-to-peak to give a full output of 5.5 watts. (This assumes that the rated voltages, 315 volts plate and 250 volts screen, are applied.) Consequently, a straight voltage-amplifier stage is used just

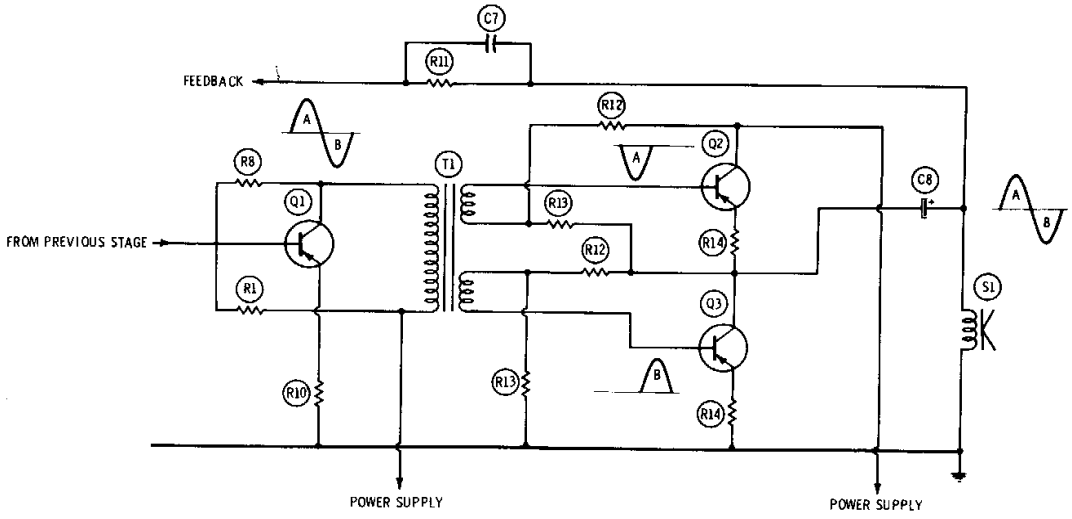


Fig. 1-9. Stacked output stage with an input transformer.

ahead of the output stage to drive it; this is called a driver stage.

Fig. 1-10 shows a typical RC-coupled circuit. This term is used because the signal is transferred from the plate of the 12AX7 tube to the grid of the 6V6 through the .02-μF coupling capacitor (C1), and the dc returns needed are made through resistors (R1). The older amplifiers use audio transformers here. In later designs it has been found that RC coupling can do the job a lot cheaper with better fidelity. The capacitor is also called a blocking capacitor by some, because it blocks the high dc plate voltage of the triode from the negative grid voltage of the 6V6. This component is a source of many amplifier problems.

Fig. 1-10 is a straight voltage-amplifier stage. A high-value (220,000 ohms) plate-load resistor is used, so the stage will not draw a lot of plate current; it doesn't have to. What is required is the developing of a very large signal voltage across the plate load to feed the grid of the 6V6, which is a voltage-operated device.

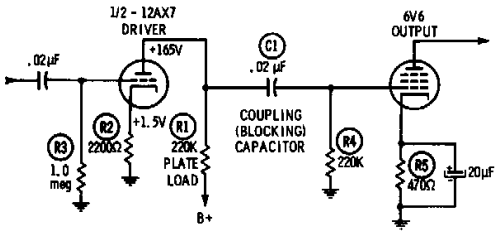


Fig. 1-10. Typical driver stage.

The driver stage is designed to have the needed signal voltage (25 pk-pk in this case) at its output. A high-gain tube, proper circuit components, and correct supply voltages work together to supply the required amount of amplification. The actual amount needed depends on the number of voltage-amplifier stages used in front of the driver. For instance, if there is a 1-volt pk-pk signal on the 12AX7 grid, this stage will have to give a total voltage gain of 25 times—1 volt in and 25 volts out (both pk-pk). The actual figures used will vary a lot between different amplifiers, but the same principle will be used in all of them.

PUSH-PULL DRIVERS AND PHASE INVERTERS

A very special type of input signal is needed for a push-pull stage: two inputs, in fact, each the exact opposite of the other, or 180° out of phase. The circuit that will produce this signal is called a phase-inverter. Fig. 1-11 shows a commonly used example.

Going back for a moment, recall that the output of a voltage-amplifier stage (Fig. 1-12) is developed by drawing plate current through the plate-load resistor. There is a complete circuit here: tube plate to B+, to B– (around the power supply through a large capacitor), to cathode, and back again to plate. As you can see, the signal voltage shows up as a voltage drop across the plate load resistor. What is needed, however, are two signals, each the opposite of the other. These can be obtained by taking advantage of a characteristic of a vacuum tube—the voltages on the plate and the cathode are always 180° out of phase. One goes down when the other goes up, and vice versa.

To get two equal output signal voltages, split the load, putting half of it in the plate circuit and the other half in the cathode, as shown in Fig. 1-11. The similarity to Fig. 1-12 is more apparent in Fig. 1-11A,

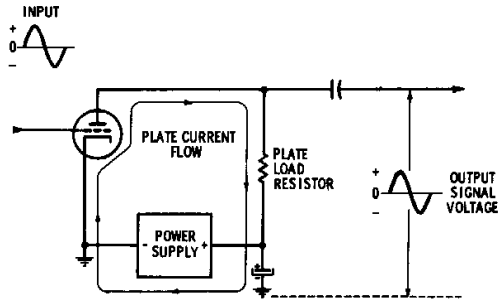
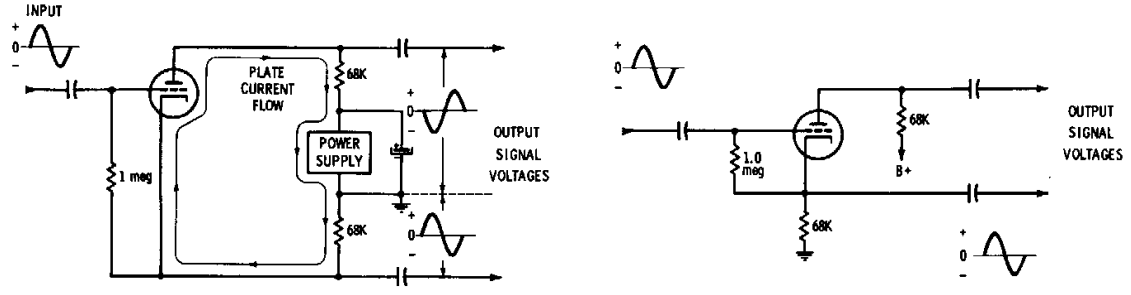


Fig. 1-12. Plate current flow.



(A) Complete current path. *(B) Conventional drawing.*

Fig. 1-11. Split-load phase inverter.

while the conventional method of drawing the circuit (with the power supply indicated but omitted) is shown in Fig. 1-11B. Since the same signal current flows through the whole circuit, a signal voltage will be developed across any resistor that this current flows through. The size or amplitude of this signal voltage depends on the size of the resistor. In the split-load circuit the two resistors are exactly the same size, so equal but out-of-phase signal voltages result across them. Notice that the plate voltage on the first half-cycle is going negative and the cathode voltage is going positive. This is because the grid voltage is going positive on the same half-cycle. Check any textbook on vacuum-tube theory for a fuller explanation.

There are other phase-inverter circuits, but this is probably the most frequently used, because of its simplicity and ease of design. In most applications this circuit will simply invert phases, but if a high-gain tube is used, a little voltage gain can be developed—which is always good.

TRANSISTOR DRIVERS AND PHASE INVERTERS

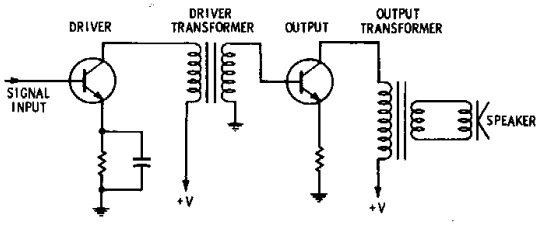
Driver stages in transistor amplifiers do the same thing as in tube types. They must deliver enough signal to drive the power output stage to its full rated output. The driver transistor must be capable of handling a little more power than the small-signal type of transistor. The driver transistor handles an average of 2 or 3 watts of actual power, and is rated at 5 watts.

The same basic circuits of tube-type amplifiers are used, with transistors replacing tubes as the active devices. Fig. 1-13 shows three typical circuits for single-ended stages. Single-ended transistor stages are common in the smaller amplifiers.

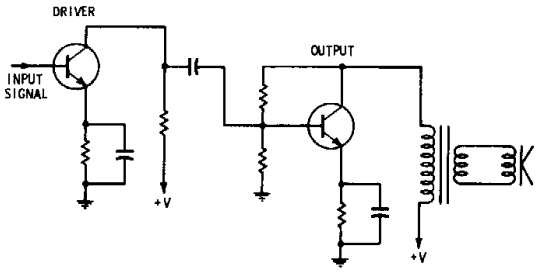
THE DIRECT-COUPLED CIRCUIT

Direct-coupled circuits have not been used with tube amplifiers since the 1920s. However, you'll find quite a few of these circuits used in the larger solid-state amplifiers, and some in the smaller ones. The advantage of this type of connection is the reduction in the number of parts, since there are no coupling devices such as transformers, capacitors, etc., needed. Also, this circuit does have a slightly greater frequency response, especially for low frequencies. Frequency range is determined by the high and low cutoff of the transistor itself, which is usually far above the range needed for music amplification.

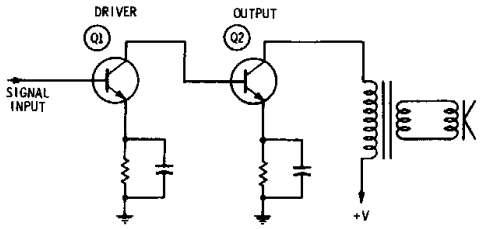
In the direct-coupled circuit the collector of the driver transistor is connected directly to the base of



(A) Transformer coupled.



(B) Capacity coupled.



(C) Direct coupled.

Fig. 1-13. Coupling methods for single-ended output.

the output transistor. The collector current variations of the driver become the base-current variations of the output. Also, the collector current of the driver determines the base bias of the output transistor; it flows from the collector through the base-emitter junction of the output transistor. Because of this interrelation, any defects in the driver transistor can upset or even ruin a perfectly good output transistor. This is one of the "mysterious" problems you'll find in some cases. It will be discussed at length in the section on servicing.

THE DARLINGTON PAIR TRANSISTORS

The single bipolar transistor has certain disadvantages when compared to tubes. For one thing, it has a very low input impedance. This makes it slightly inefficient when used as an input stage to a high-impedance pickup, such as that used with a guitar or microphone. Its voltage gain is also low. The loss of gain and the low impedance can be overcome by

using a "bootstrap circuit" and more transistors. However, there is an easier way, and one that you will find used in quite a few of the later model amplifiers.

The common-collector transistor amplifier circuit has a very high input impedance, but not too much gain; the common-emitter circuit has good gain, but a low impedance. If we connect these circuits in "cascade," as in Fig. 1-14, we can use the best features of both. The common-collector stage now drives the common-emitter stage by direct coupling. The device has a very high input impedance, suitable for direct connection to a pickup or mike, and a very high gain considerably more than the gain of either transistor alone.

The Darlington amplifier, also called a "Darlington pair," is built into a single package, with only three external leads, as shown in Fig. 1-14. It looks exactly like a plain three-lead transistor. However, if you replace one with a single transistor, you'll wonder why the amplifier has such low gain, and usually high distortion! Unfortunately, these Darlingtons are drawn on some schematics as a single transistor. Be sure to check the parts list. In all cases, this transistor will be identified as a Darlington (sometimes they leave off the "pair"). So, watch out for this. If you find an amplifier with only a single transistor in the input, where there would normally be at least two, look out. This is probably a Darlington. (Details on how to test this unit on a transistor tester are given later.)

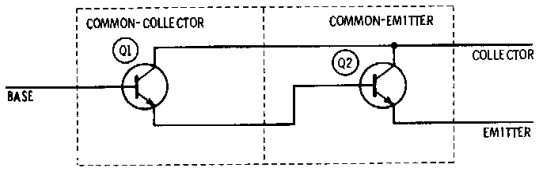


Fig. 1-14. Darlington pair—two transistors in one case.

In cases of emergency, you can make up a Darlington pair from two equivalent silicon transistors. Most of the Darlingtons found in use in amplifiers seem to be silicon types. Germaniums have a little bit too much leakage for use in this kind of application. When you take the old transistor off the PC board, you'll have the standard three holes in the board for the emitter, base, and collector.

By using two identical silicon transistors, you can connect the two collectors together (twist the leads) and put these into the original collector hole. The base of the transistor Q2 is twisted directly to the emitter of transistor Q1. There is *no* circuit connection to this junction. The emitter of Q2 goes to the original emitter hole, and the base of Q1 to the original base hole.

In practically all capacity-coupled circuits, this setup works very well without changes. If the output of the Darlington is directly connected to the base of the following transistor, check its bias to make sure that this is the same as it was before (get this voltage from the schematic.) If the base bias of the driven stage is too high, try using transistors with a lower beta to fabricate the Darlington pair. This will usually correct the bias problems. Check the circuit with the scope for distortion.

THE PREAMPLIFIER STAGES

The signal voltage required at the input of the phase-inverter or driver stage determines the amount of voltage gain needed in the preceding stages of the amplifier. If the type of phase-inverter stage having a gain of one, or unity, is used, the peak-to-peak signal voltage will have to be roughly twice the bias voltage of the output tubes to produce full output.

For example, if the pickup has an output of 50 millivolts (50 mV or .050 volt), and if a signal voltage of 50 volts pk-pk is needed at the grid(s) of the output stage, a total voltage amplification of 1000 times is necessary. This sounds pretty high, but it is not; many amplifiers have voltage gains up to a million! It works very simply: if a stage has a gain of 10 and is followed by another just like it, the total is the product of the individual gains, or 100, from these two stages alone. Adding another stage with a gain of 10 will give 1000 (10 × 100), and there you are. Modern tubes and transistors are capable of many times this amount of gain. There are other troubles, however, when the gain is high.

The main consideration in designing high-gain voltage-amplifier stages is not gain as much as noise. All high-gain stages have a tendency to make noises internally—random noise from current flow in resistors, shot-effect noise in tubes, and so on. This is the limiting factor in getting a lot of gain out of a single stage. The answer is to use more than one stage to get the amplification needed. By doing this, each stage can work at its maximum noise-free amplification level.

Another troublesome thing is distortion. Every one of these stages must be designed for absolutely linear operation. This means that the signal in the output must be exactly the same shape as the signal in the input. If the stage changes the waveform in any way as the signal passes through, a very poor sound quality results due to distortion. This is the second major consideration.

There are several ways of avoiding distortion. As a matter of fact, you do not have to worry about it,

as far as the original design is concerned. This work has all been done for you by the engineer who built the amplifier. In all but the very cheapest amplifiers, distortion and noise will be at a very low level when the instruments are new. What you have to do is put them back in the same condition! Although you don't have to design amplifiers, you do have to know how and why the circuits work so you can tell when they are working correctly.

Many of the better amplifiers use built-in correction circuits to hold the distortion down to a very low level. These are usually inverse-feedback circuits. In them a part of the output of the amplifier is fed back into an earlier stage in such a way that it cancels out some of the distortion. While this does reduce the overall gain of an amplifier, it also improves the tone quality so much that the small loss of gain does not matter. The loss can be corrected by using another voltage-amplifier stage if necessary.

Feedback voltage must get back into the amplifier in the right phase so it will be degenerative—tending to stop oscillation. If the phase is wrong, it will be regenerative—tending to cause oscillation. When certain components are replaced, there is a possibility of wrong connections. If an output transformer is replaced, for example, the amplifier can oscillate if the phase of the feedback is reversed. Other causes of oscillation will be taken up later in the section on servicing.

Distortion is not always easy to detect and cure. The ear alone is seldom accurate enough to pinpoint the actual cause or type. It is necessary in bad cases to use an oscilloscope and very accurately shaped test signals to find and fix this kind of trouble.

THE "BOOTSTRAP" CIRCUIT

Previously we mentioned "bootstrapping" a transistor to get higher input impedance. Fig. 1-15 shows how this is done. Note the high value of the emitter resistor, as compared to the low values used in other common-emitter circuits. This high resistance holds the transistor current down to a very low value, around 300 microamperes. There is no emitter bypass to ground, so practically all of the base signal appears across the 4700-ohm resistor. From here, it is coupled by the 50-μF capacitor to the bottom end of the base resistor.

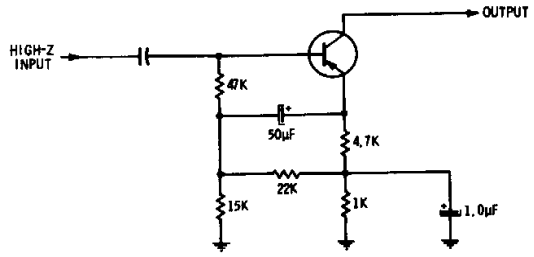


Fig. 1-15. Bootstrapping a transistor input stage to obtain a high input impedance.

Due to this coupling, the base resistor "sees" the same signal voltage at top and bottom ends. So, this resistor looks like an *open circuit* to the input signal! This is a very high impedance. The absence of an emitter bypass also makes the impedance higher. In other words, we have a very high degenerative feedback in such a stage.

This reduces the gain of the stage, but allows high-impedance devices like microphones and pickups to develop a high signal across the high-impedance input. Degeneration also helps to eliminate distortion due to mismatching. We can always get back any gain lost in such stages by adding another amplifier stage following the bootstrapped input—a Darlington amplifier for example.

It's important to remember this, for you could be misled into thinking it was defective, due to its low gain; check the schematic to see if it is bootstrapped. If so, low gain is all right.

Chapter 2

Special Signal Circuits

The basic function of the guitar amplifier is to increase the sound of the instrument so it can be heard under many different conditions—from small practice rooms to large concert halls. Yet electronics offers many possibilities for adding variety to the basic guitar sound. The location of the pickup influences the signal; some guitars use as many as three in different positions for various effects. Tone control circuits in the amplifier itself can make the sound brilliant or mellow. Other special circuits—echo (reverberation) and tremolo—can be added by separate units or can be built into the amplifier.

THE PICKUPS—TYPES AND CONSTRUCTION

At the input of the amplifier is the pickup itself—the device that converts the motion of the guitar strings into electrical signals. The first type used was a contact microphone constructed as shown in Fig. 2-1. The correct technical term for any of these things would be "electromechanical transducer," but they are called pickups for convenience.

The contact mike is just a microphone element of any kind—crystal, dynamic, etc. Instead of having a diaphragm like the voice-operated types, it has a coupling of some kind, so it can pick up only the vibration of the surface with which it is in contact (theoretically!). Actually, due to the high gain that is required, this kind of mike picks up many sounds very well—talking close by, the rubbing of clothing on the guitar, any jar that is given the instrument, and so on. Now the contact mike has been replaced almost entirely by the magnetic pickup. This responds only to a motion of the metal strings through the magnetic field of the pickup coil and has no microphonic effects that produce undesirable sounds.

Fig. 2-2 shows how this works. Only one coil is shown, although there is normally one for each string; they all work in the same way. All strings are made of metal; single strands are used for the higher pitch, and wrapped strings for the bass. The pickup consists of a small permanent magnet wound with a great many turns of a very fine wire. The metal string vibrating in the field of the magnet causes this field to move. Since the coil of wire (pickup coil) lies in the moving magnetic field, a small electric current is generated in the coil.

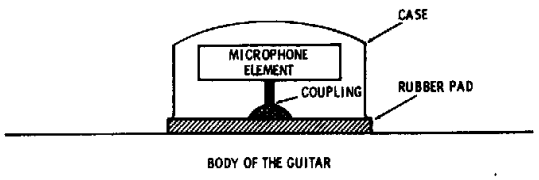


Fig. 2-1. Typical contact microphone.

This electrical signal will be a duplicate of the physical motion of the string. The physical motion, of course, is the pitch of the string or the musical note that it makes when plucked. The electrical signal is the same frequency as the musical note, and all that is necessary is to amplify it as much as is desirable.

The original magnetic pickups were attachments designed for mounting on the original acoustic guitars —those with no electronic amplification. Fig. 2-3 shows a typical mounting for one of these. A single, long, flat coil in a metal shielding case was used, and

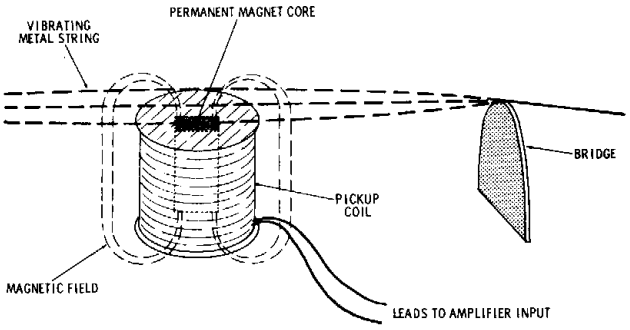


Fig. 2-2. Operation of a magnetic pickup.

a clamp was provided to hold it tightly in place under the strings. Some models had volume controls in the same assembly.

In specially built electric guitars the pickup coils, volume and tone controls, etc., are installed in cutouts in the body of the instrument where they are covered with chromed metal plates or plastic covers. There are other controls and special effects used on the custom models, which are discussed later.

All of the pickups use the same basic circuit shown in Fig. 2-4. If individual coils are used for each string, they are connected in series or parallel; the whole pickup unit is connected across a volume control of from 0.5 to 1.0 megohm or more. The simple high-cut tone control shown may be mounted on the guitar itself. A shielded coaxial cable is always used to connect the pickup to the amplifier; this eliminates hum, electrical noise, etc., from the signal. If the interconnecting cable is fairly long, say more than about 10 to 15 feet, a low-capacity cable should be used. Very small cable has a high shunt capacity and will cut down on the transmission of high frequencies. Most standard microphone cable is fairly low capacity, and up to 50 feet can be used without trouble.

Standard phone plugs and jacks are the type of connectors most commonly used. The connections on these must be kept clean and tight to get rid of any noise and hum. Full details on how to handle these plugs and make repairs to the mike cables will be given in the section on servicing.

TONE CONTROLS

All except the very smallest amplifiers have some sort of tone-control circuit. These do not change the fundamental tone of the instrument—that is, the pitch or frequency of the string. However, they can change the characteristics of the amplifier by increasing or de-

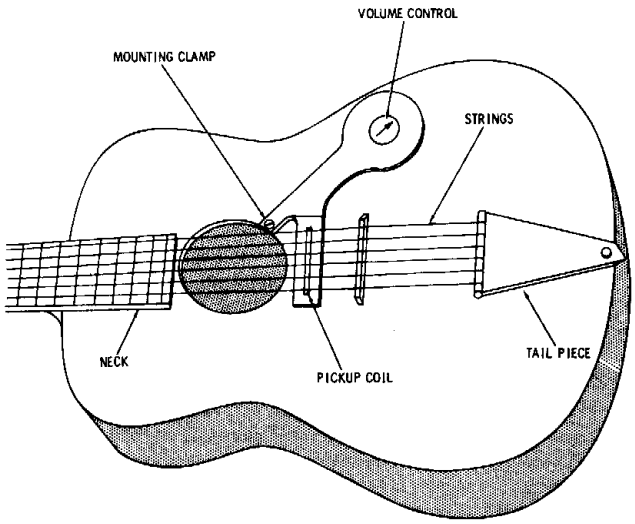


Fig. 2-3. Acoustic guitar with pickup-coil attachment.

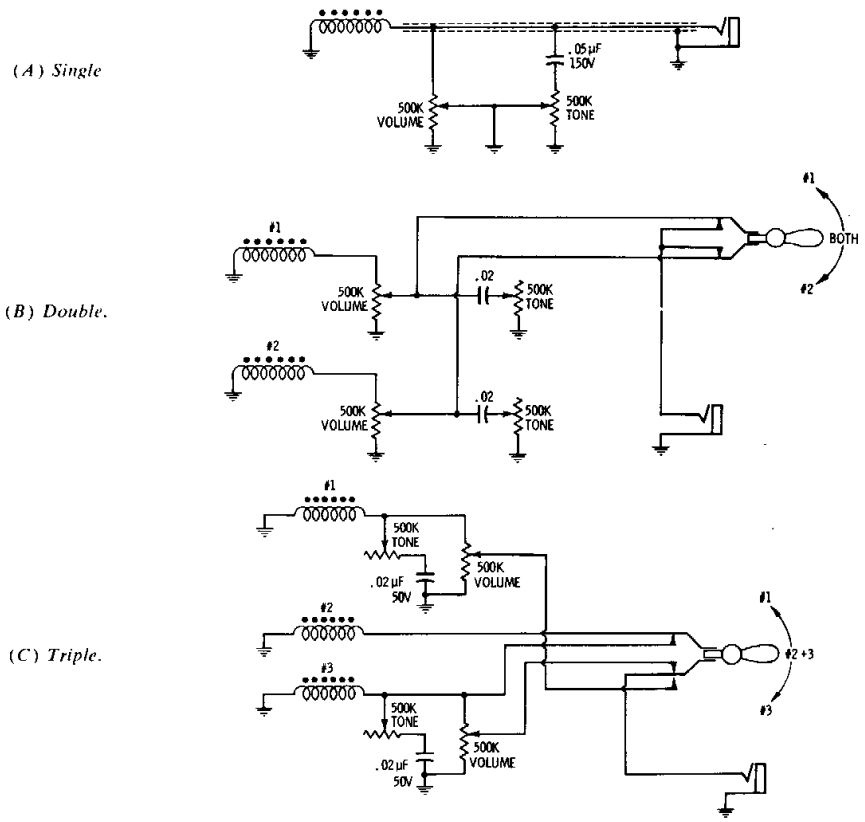


Fig. 2-4. Pickup circuits.

creasing the amplification of high or low notes, depending on the control setting.

The simplest tone control is what is known as a high-cut type, as used in Fig. 2-4. Basically, it looks like Fig. 2-5. A capacitor has one valuable characteristic: it shows a much lower impedance to high-frequency signals than to low frequencies. If it is placed across a signal circuit at any point in the voltage amplifier, the high-frequency response will be cut. The capacitor will short out the highs by giving them a low-impedance path to ground. This is called a high-cut circuit, because it cuts down on the high frequencies and gives the amplifier a lower tone. This type of tone control does not increase the bass tones; it simply takes out some of the highs and makes the bass sound bigger by comparison.

In order to vary the amount of high cut, a variable resistor is added in series with the capacitor (Fig. 2-5). The size of the resistor and the capacitor will determine how much of the highs are taken out or left in. If the control is set to its lowest resistance posi-

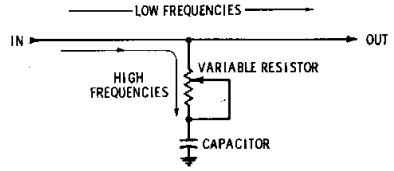


Fig. 2-5. High-cut tone-control circuit.

tion, all of the capacitance is across the circuit, and the lowest tones will be prominent. If the variable resistor is set to the maximum resistance position, in effect the capacitor is taken out of the circuit, and the high tones are present, because the path to ground is now a high resistance. After the tone control, the signal goes on to the next stage of the amplifier.

FEEDBACK TONE CONTROLS

In the more expensive instruments, a different type of tone control is used, involving what is called negative feedback. This either boosts or cuts the bass and

treble frequencies. Since it is a pretty complicated circuit, the details of its design will not be discussed. However, it can be found in any good electronics textbook under bass boost and treble boost tone-control circuits.

A feedback tone control can increase the amount of bass frequencies in a tone (bass boost) or cut them; the same thing can be done with the treble frequencies. Neither of these actions will affect the other. The simple high-cut tone control, of course, affects all frequencies somewhat. The basis of operation is the use of selective feedback—a network of resistors and capacitors that feeds back a part of the output signal into the input. By changing the amount, and in some cases the phase, the input signal can either be built up or lowered at selected frequencies. Inverse feedback always lowers the gain of an amplifier but improves its fidelity. If a large amount of bass frequencies are fed back, for example, the gain of the amplifier for bass notes is reduced. By cutting down on the amount of signal fed back, the gain is returned to normal (bass boost). By changing the frequency of the feedback circuits through the use of different resistor and capacitor values, the same action can be obtained for treble tones.

TREMOLO

Tone controls have no effect on the action of the amplifier; they simply change its frequency response or volume a little. The special effects result in a whole new character to the sounds. There are three of these in common use: tremolo (a variation in volume level), vibrato (a variation in frequency or pitch), and echo or reverberation.

Tremolo is basically pretty simple. If the bias of an amplifier stage is raised or lowered, the volume changes. Almost any subaudible frequency can be used to give a pleasing "vibration" effect to the musical tone. This causes the two effects to be confused; unless you have a very keen ear for musical notes, you can easily get tremolo and vibrato mixed up since they do sound a lot alike.

A tremolo effect can be created by varying the bias voltage on any amplifier stage at any desired frequency. The typical circuit will use frequencies from about 1 Hz up to 50 or 60 Hz. The average amplifier has a tremolo rate of about 10 to 15 Hz. Fig. 2-6 shows how this circuit works. Typical waveforms are included. Note that there are two controls shown. In most amplifiers these are marked STRENGTH and SPEED, meaning amplitude and frequency.

The heart of the tremolo circuit is a very low frequency oscillator, the output of which can be varied in frequency (by the SPEED control) to give the rate of tremolo wanted. The STRENGTH (amplitude) control varies the voltage of the output. At its low end there will be a barely perceptible quaver in the note; at the other extreme, the tremolo will consist of variations from fairly high to fairly low volume.

The output of the low-frequency oscillator might be called a slowly varying dc voltage for simplicity. This is fed, through isolating resistors, into the bottom of the grid circuit of the desired amplifier stage. There it affects the grid-bias voltage by adding and subtracting to the bias already present in normal operation. As a consequence, it changes the volume at the output of the stage. The tremolo effect, once added to the signal, goes on through all of the following amplifier stages.

Examine an actual tremolo circuit used in a typical commercial amplifier (Fig. 2-7). The 6SQ7 tube is a phase-shift oscillator; notice the network of capacitors and resistors connected between the plate and the grid of the tube. This takes the signal from the plate, delays it in phase as it passes through, and feeds it to the grid in just the right phase to cause oscillation. The frequency of oscillation in these circuits depends on the values of the resistors and capacitors; it can be controlled by varying either one of them.

Since variable capacitors are big, a variable resistor is used—in this case the 500k control shown con-

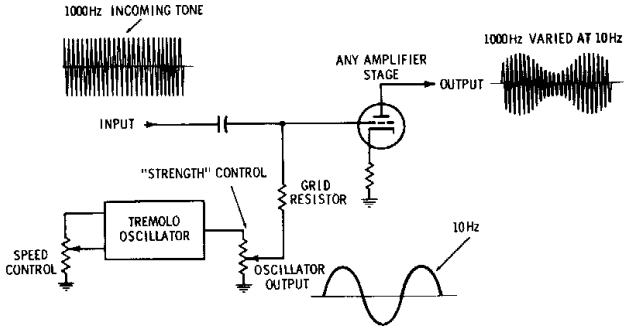


Fig. 2-6. Tremolo circuit.

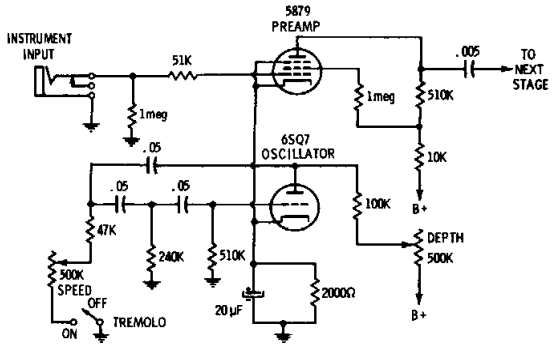


Fig. 2-7. Phase-shift oscillator tremolo circuit.

nected to the tremolo on-off switch. The output of this circuit will be very low frequency oscillation.

The bias variation is applied to the 5879 preamplifier stage. When the two cathodes are coupled together, the bias voltages on both stages vary simultaneously. This changes the gain and consequently the amplitude of the output of the preamp tube. Any instrument connected to the input of the 5879 preamp tube will have a tremolo in its output that can be varied by the setting of the tremolo controls.

There are two controls: frequency, the variable resistor in the oscillator circuit itself, and amplitude, the variable resistor in the B+ supply circuit to the oscillator plate. You will find these called STRENGTH (amplitude) and SPEED (frequency) in most amplifiers for simplicity. In one make they are labelled DEPTH (amplitude) and RATE (frequency). No matter what names are used, they do the same thing.

The amplitude control works by increasing or reducing the plate voltage of the oscillator. This does not have much effect on the frequency of a phase-shift oscillator, which is pretty stable, but it will affect the amplitude or strength of the oscillations. A high amplitude oscillation will cause a greater change in the cathode voltage and thus will give a much more noticeable tremolo in the preamp output. This is why it is called depth in one make: it varies the depth of the tremolo imposed on the original tone.

You will find several different versions of the amplitude control, but the effect is always the same. For instance, the amplifier shown in Fig. 2-8 is a high-powered unit with two 6L6s in the output, and feeds the tremolo bias directly to the output tubes. Here a 6AU6 tube is used as the tremolo oscillator (a phase-shift type), and the voltage variations are coupled into the grid return of the 6L6s through a 0.1-μF coupling capacitor from the 6AU6 plate and the strength control. In this case the strength control is a divider across the tremolo oscillator output.

The tremolo circuit in Fig. 2-9 is somewhat more involved than the previous ones. The phase-shift oscillator is like all the others although the actual controls are in a remote control assembly. However, the tremolo signal is applied to the amplifier in a very different manner. From the oscillator the tremolo signal goes to an inverter that puts out two tremolo signals—one at the plate and one at the cathode, each 180° out of phase with the other. The signal from the guitar is also split (by V4A) into two signals of opposite phase—one chiefly high frequencies and the other low frequencies. The corresponding tremolo signal is added to each guitar signal (in V5A and V5B), and then the outputs are combined. The purpose of all this circuitry is to eliminate any sound of the tremolo from the amplifier output when the amplifier is on but the guitar is not being played. This is accomplished by using the two out-of-phase tremolo signals; when they are combined without a guitar signal, they cancel out.

In the other circuits the tremolo voltage varies the bias; in Fig. 2-10 the ac signal from the tremolo is fed through a comparatively large capacitor to the screen grid of a pentode amplifier tube. The previous circuits

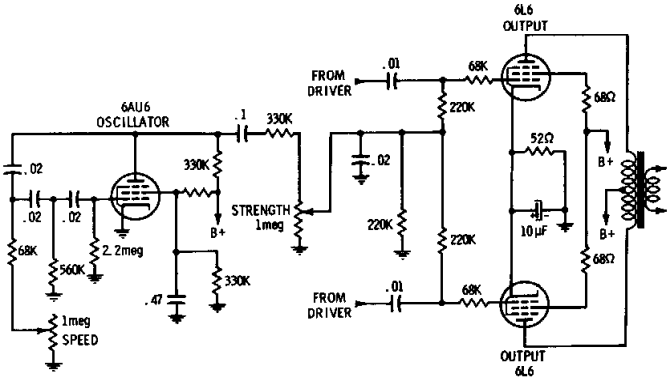
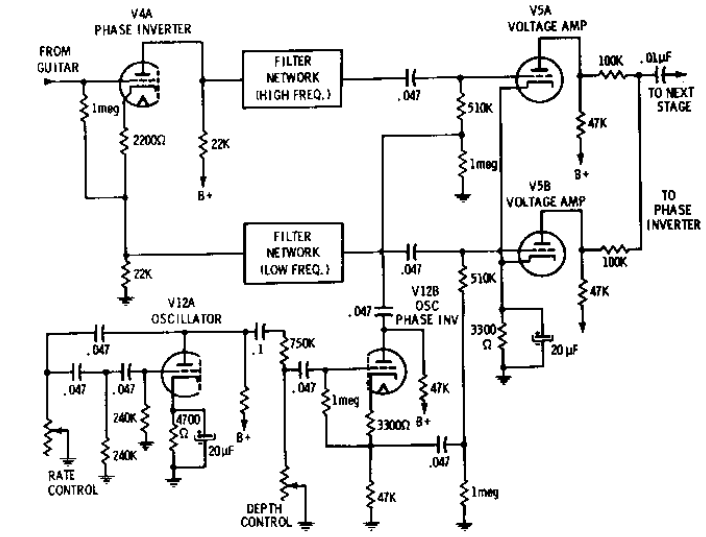


Fig. 2-8. Tremolo applied to grids of output tubes.



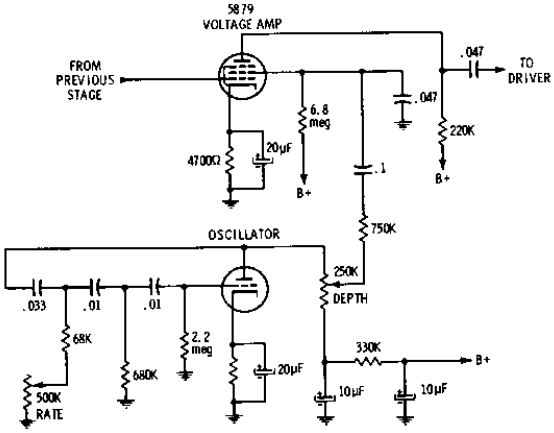


Fig. 2-10. Tremolo signal coupled to screen grid.

have been directly coupled—all resistors. This one is coupled through a capacitor. The action remains the same. There is a comparatively small screen-grid voltage applied to this tube. Look at the size of the screen-grid dropping resistor (6.8 megohms). As a result, the tube has a screen-grid voltage of about 20 volts. If an ac voltage varying about 10 volts peak to peak is fed through the big capacitor, the screen-grid voltage is actually changing from 20 to 30 and back to 10 volts. The actual voltage on the screen at any given instant will be the sum of the residual dc voltage through the B+ supply resistor plus the instantaneous value of the tremolo voltage coupled through the blocking capacitor. Since the amplification factor of a tube can also be changed by the screen-grid voltage, this adds the tremolo effect to the signal going through the tube at that time. (Very old radio sets used this circuit for volume controls; they changed the screen-grid voltage on the rf amplifier stages.)

Fig. 2-9. Tremolo applied as two out-of-phase signals.

All of the circuits shown in the preceding figures can be used in transistorized amplifiers. There is no difference in the basic operation. This also applies to any other special-effects circuitry.

The Light Dependent Resistor

A novel method of coupling the tremolo oscillation voltage into the voltage amplifier circuits involves the use of a light dependent resistor. Fig. 2-11 shows this circuit. A light dependent resistor (LDR for short)

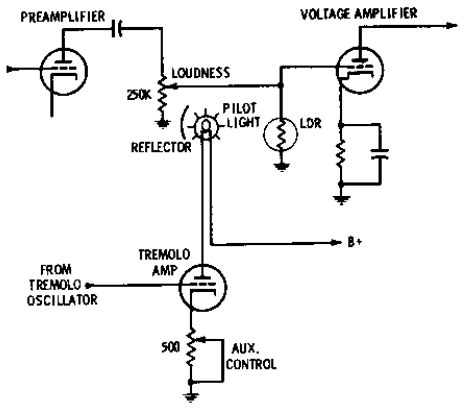


Fig. 2-11. Light dependent resistor (LDR) used to couple tremolo to signal channel.

is a photoelectric cell in which the resistance of the unit depends on how much light is falling on it. A variable resistance can be used as a volume or loudness control; there is one just ahead of this. By making the LDR vary in size, there is in effect another volume control in the same circuit that will raise and lower the volume just as the loudness control does. However, for this application the variations must be in step with the vibrations (slow voltage changes) of the tremolo circuit—from about 3 to 50 Hz. So, instead of coupling the tremolo voltage directly into the bias circuit, an LDR is used. The tremolo oscillator has no direct connection to the sound circuits; its plate circuit contains a small pilot light. As the signal changes, this light gets brighter and dimmer. The light is focused on the LDR, making its resistance change. This varies the volume in the signal channel, adding tremolo to the signal.

One reason for the use of the LDR is to isolate the tremolo oscillator from the signal circuits. Unless some precautions are taken, the low-frequency oscillation will go through the amplifier when the guitar is not being played and give an unpleasant sound in the output. With this system no oscillator signal is introduced into the guitar signal circuits; there is tremolo in the output only when there is a musical signal going through the amplifier.

Usually the LDR and the lamp are contained in a single unit which is drawn on a schematic as shown in Fig. 2-12. Either incandescent or neon lamps may be incorporated into the units, depending on the voltage used to excite them.

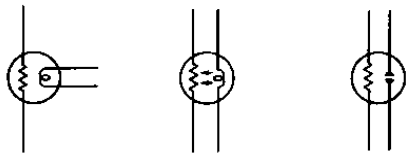


Fig. 2-12. Schematic representation of light dependent resistors and lamps.

VIBRATO

A true vibrato is very difficult to get, electronically. It would involve a very complicated circuit using differential phase-shifting that would be very hard to make adjustable. Most manufacturers use a mechanical lever action on the tailpiece of the guitar; the player strikes a chord, then moves a long handle back and forth. This changes the tension on all strings at the same time, alternately raising and lowering the pitch of the chord. Fig. 2-13 shows two vibrato units, one functioning as a tailpiece only and the other combining an adjustable bridge with the tailpiece.

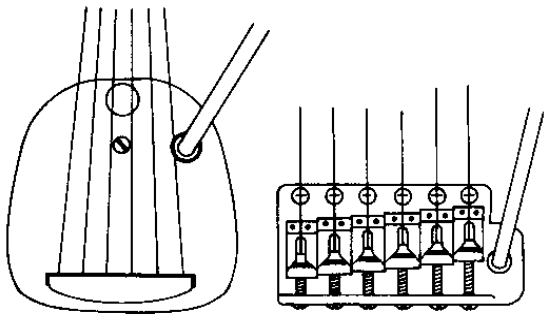


Fig. 2-13. Mechanical vibrato units.

NOTE: You will find the two terms—tremolo and vibrato—used interchangeably, even in some of the catalogs. By a strict musical definition, they are not interchangeable. If the circuit varies the volume of the tone, it will be a tremolo no matter what is on the control knob. If the pitch of the tone varies, then it is a vibrato. Frankly, both effects sound exactly alike to the untrained musical ear, so it probably doesn't make a lot of difference which term is used.

ECHO OR REVERBERATION

Echo or reverberation is a very popular effect of late. It is used in many popular recordings, musical arrangements, and so on. An echo effect is obtained by taking off a part of the signal, delaying it slightly, and then adding it to the original signal. The original note sounds, and a fraction of a second later there is an echo. This is done by changing phases in the signals.

Phase means a time relationship between any two similar electrical signals; it is generally used with reference to ac signals only. If one signal starts out and is followed a fraction of a second later by another signal just like it, the second signal is lagging in phase with reference to the first signal. This, of course, is the same effect you get if you yell into a canyon. First you hear your own voice come back from a nearby cliff, and then, a wee bit later, it comes from a more distant cliff. It is the same thing: echoes.

If the echoes are so close together that the listener can't separate them, the sound is called reverberation. The only difference between echoes and reverberation is the length of time or amount of delay between the signals.

To get an echo effect electronically, only a part (approximately half) of the signal is taken off. The original goes on through the amplifier; the part that is taken off goes through a special circuit which

causes it to lose time—it is delayed. The amount of delay is regulated by controls in the echo circuitry; also the amplitude or the strength of the delayed signal can be varied. When the original and the delayed signals are combined in a second stage, there is an echo effect; the original signal is heard, and, a small fraction of a second later, the delayed or echo signal is heard. Fig. 2-14 shows a block diagram.

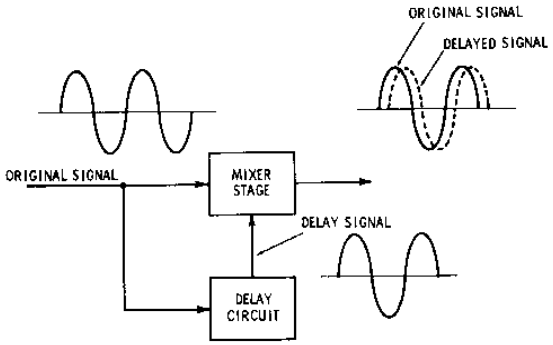


Fig. 2-14. Using signal delay to produce echoes.

Most circuits use a mechanical delay line for echo circuits. This looks like a pair of old-fashioned spiral screen-door springs in a little box. Actually, they are very carefully designed springs having very precise travel times, as will be seen. A speaker is mounted on one end of the two springs. This is not a true speaker, but a speaker-motor that converts the electrical signal into mechanical vibrations, just as a speaker does. This puts the sound signal onto the ends of the two springs. It travels the length of the two springs in very slightly different times due to the way the springs are wound. A typical time used by one major manufacturer is 29 milliseconds for one spring and 37 milliseconds for the other (1 millisecond equals .001 second). The delay effect is accomplished in the springs themselves. At the receiving end of the springs, there is a small microphone or its equivalent. It changes the mechanical vibrations that have traveled down the springs back into electrical vibrations which become the phase-shifted (delayed) signal that is combined with the undelayed, or original, signal.

The reverb circuit used in a commercial guitar amplifier is shown in Fig. 2-15. The signal comes in at the preamp grid; it is amplified, and fed to the "reverb-in" amplifier tube. From the plate circuit of this tube there are two paths for the signal to follow. One is directly to the input of the next stage through the resistor network shown above the reverb unit. The signal that follows this path is the undelayed signal.

The other path is through the reverberation unit. This consists of a speaker or reproducer, the delay springs, and the pickup unit. The signal is delayed as it passes through the springs, but it goes through the alternate path at normal speed. There are two signals coming from the same source—one is normal and the other lags behind by 29 or 56 milliseconds. They are combined in the plate circuit of the reverb output amplifier tube and sent along to the next amplifier stage.

The reverb control determines the proportion of delayed signal used. You can use just a little or a lot, depending on how deep you want the reverb effect. This, in effect, is a reverb volume control.

Transistor Units

Fig. 2-16 shows a reverberation unit with transistors. This unit is designed as an attachment instead of a part of the original amplifier. The basic action, of course, is the same. The signal comes in at the input jack to the base of Q1, which is an emitter-follower circuit in order to match the high impedance output of the amplifier. This is fed to the base of the second transistor, and coupled to a third transistor which drives the reverb springs. The pickup at the output end of the springs feeds its signal to the base of the output transistor (a common emitter circuit), which in turn feeds the output jack.

The reverb control is a 10,000-ohm variable resistor across the pickup. A foot switch can be used to cut the reverb effect in or out as desired. It does this by grounding the junction of two .005-μF capacitors in

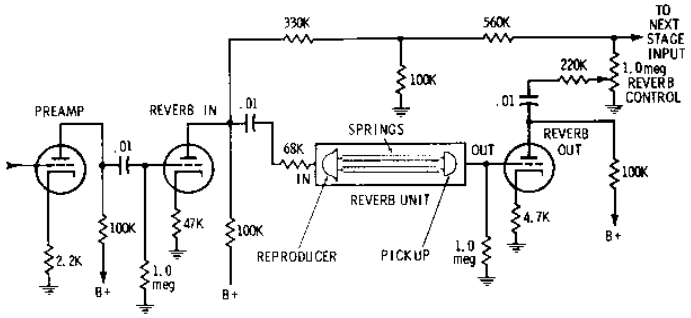


Fig. 2-15. Reverberation circuit.

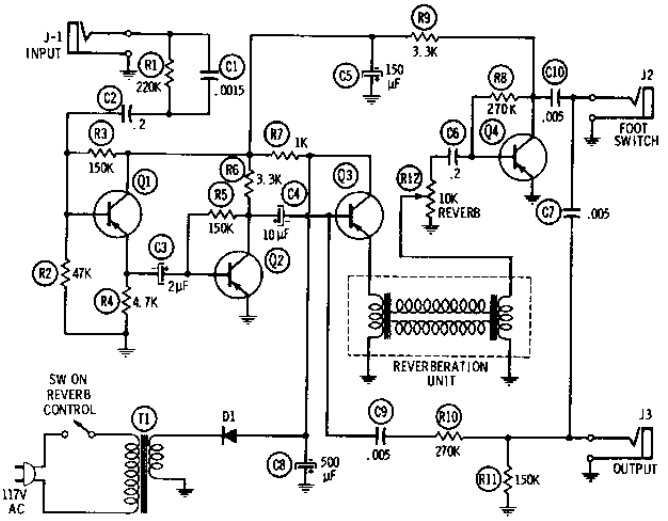


Fig. 2-16. Transistor reverberation unit.

series in the output circuit, eliminating the reverb signal.

MULTIPLE INPUT CONNECTIONS

One feature found in all but the smallest guitar amplifiers is multiple input connections. These are provided so that several instruments can be connected to the same amplifier at the same time. If two guitars (a lead and a rhythm), a bass, and a violin are plugged in together, for example, the whole band can use a single amplifier.

Some of the amplifiers have microphone inputs as well. These have slightly higher gain than the instrument inputs to compensate for the low output of microphones and to give ample volume for vocal choruses.

The main problem, of course, is not gain, but of mixing the various inputs. All of these must be controllable so that the volume of one instrument can be raised to take a solo passage, for example, while the rest stay below him. One volume control must not affect any of the rest. Instead of connecting them all together, it is necessary to isolate them by means of mixer stages. Correctly built, these give some gain too.

Fig. 2-17 shows a diagram of the most common mixer circuit, with four instrument inputs and a mike input. Each one has its own volume control; a master volume control to adjust the gain of all inputs at the same time is used later in the amplifier circuit.

Here (Fig. 2-17) the output of each instrument goes to the grid (input) of a triode tube. For economy, one of the popular twin-triodes (12AX7, 12AT7, etc.) is used. All of the grids are separate, but notice that all of the plates are tied together. They are connected in parallel, but with isolating resistors (R1, R3, R6, R7, and R9) in series with each plate circuit. These will not affect the gain, but they will help to keep one circuit from interfering with another. You may find isolating series resistors used in the grid circuits, too.

Individual volume controls are used, ordinarily in the input of each stage, although they will work the same in the plate circuits.

The microphone input uses a pentode tube instead of the triode for higher gain. Because of the increased gain, noise becomes a problem again. So, the tube type shown (5879) is a nonmicrophonic pentode especially designed for use in such a stage as this. The output goes to the same common line; all of the signals are mixed here and are fed through coupling capacitor C1 into the next stage of the amplifier.

Twin-triodes are shown in Fig. 2-17. You will probably find triple triodes (Compactrons) in some amplifiers.

TRANSISTORIZED MULTIPLE-CHANNEL INPUTS

You will find similar mixer circuits used in transistor amplifiers. In the circuit of Fig. 2-17 by replacing the tubes with transistors we have a transistor four-channel mixer. All ordinary bipolar transistors can be regarded as "triodes," so they can replace a triode tube in the mixer with the greatest of ease. The outputs will be combined just as before. You may find an extra amplifier stage between the input and the

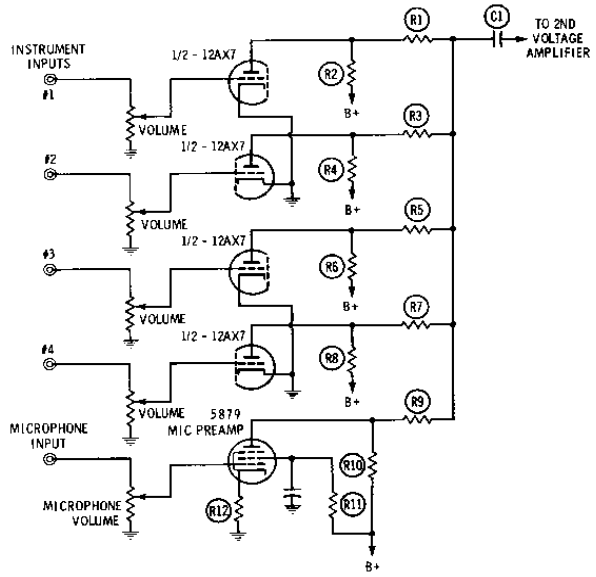


Fig. 2-17. Typical circuit for a 4-channel mixer.

mixing circuit, but basically the circuit will be just the same.

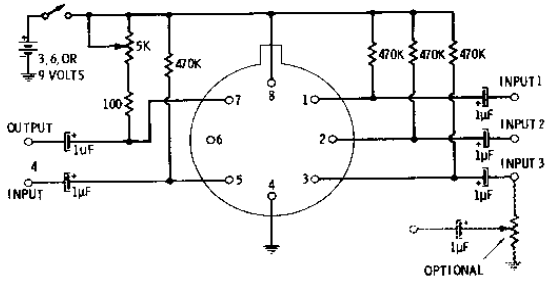
INTEGRATED-CIRCUIT MIXERS

Although, to the best of my knowledge, no integrated circuits are being used for mixers in commercial guitar amplifiers as this book is being written, I have no doubt that they will show up in the very near future. Fig. 2-18A shows a typical circuit using a Motorola HEP-581 "4-input Gate" IC. This is a small, round 8-pin IC, not much bigger than a TO-5 cased transistor. These ICs may be found soldered permanently (sic) into the circuit, or made to plug in for quick replacement.

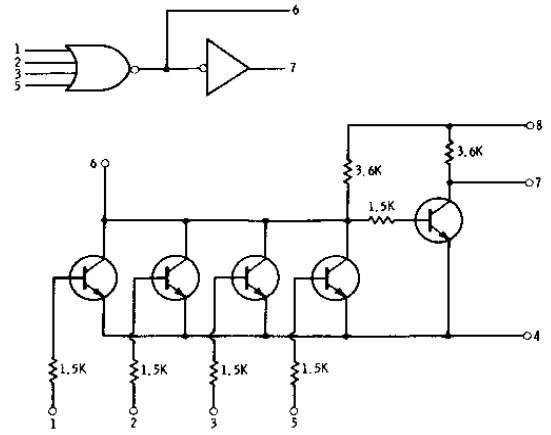
This unit is one of the simplest of the integrated circuits. It contains only five transistors and seven resistors. The internal circuitry is shown in Fig. 2-18B. This unit is not difficult to test. First, be sure that the normal input voltage is present on pin 8, then check each output with the scope, feeding a test signal into each of the four inputs. If there is no output signal and all of the external circuitry is alright, that is, no shorted or open coupling capacitors etc., then the IC is probably bad. Try a new one.

THE INTEGRATED-CIRCUIT AMPLIFIER

Certain ICs can be used as preamplifiers, also. Fig. 2-19 shows one of these, with the circuit, and the internal connections of the IC. Here again, the same



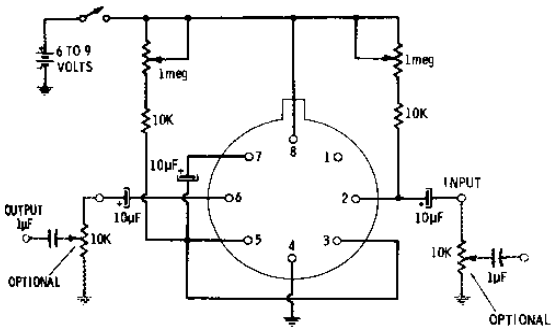
(A) Used as a 4-input mixer.



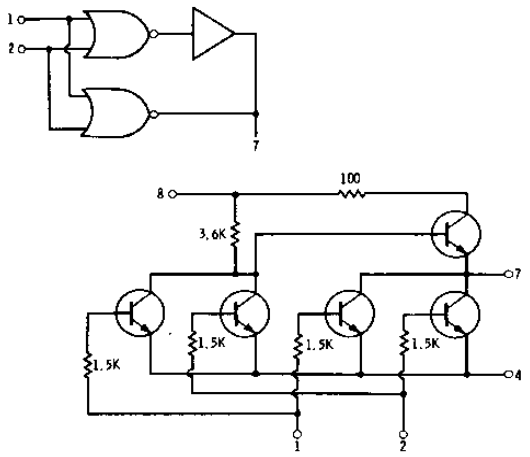
(B) Schematic diagram.

Fig. 2-18. Motorola HEP-581 4-input gate.

test methods can be used. First make sure that the IC has the correct voltage supply, and then check the output for signal level. In this one, you should find a good-sized voltage gain. The actual gain depends on the circuit, size of load resistor used, etc.



(A) Used in high-gain amplifier.



(B) Schematic diagram of half the unit.

Fig. 2-19. Motorola HEP-582 dual buffer.

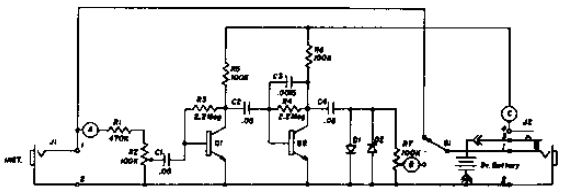
In the small amplifier section of this book, you'll find amplifiers which are "all IC." The whole amplifier circuit, including the output stage, is built in an integrated-circuit package. At this time, these are limited to about 5 watts rms maximum power, but you may find them later on with greater power output.

SPECIAL EFFECTS UNITS

There are several "special-effects" units which are used with electronic amplifiers to give the "new sound." You may find these in separate cases, plug-in, or built into the circuit of some of the more elaborate amplifiers. Separate or built-in, they all work the same, and can be checked the same. Most of these are fairly simple, and the standard tests can be used to troubleshoot them.

The Fuzz Box

The simplest of the special-effects units is called a "fuzz box", "scrambler" and so on. It does just what its name implies. Fig. 2-20 shows the schematic of a typical unit. The signal from the guitar is fed through the input jack to a standard two-stage transistor amplifier. Note the reverse-paralleled diodes D1 and D2 shunted across the output of the second stage. When the signal reaches a certain level, these diodes will go into conduction. This will clip the peaks from the signal waveforms; one clips the positive peaks, the other clips the negative peaks. Fig. 2-21 shows the input signal and the output signal after clipping.



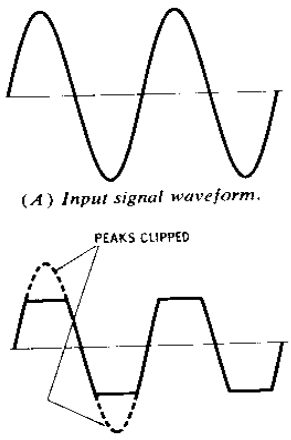
Courtesy Allied Radio Shack

Fig. 2-20. Schematic diagram of a "fuzz-box" circuit.

This clipping action, and the resulting almost "square-wave" shape, gives the tone its characteristic "fuzz" sound. The higher the signal level, the greater the clipping action. The volume control R2, at the input, determines the level of signal at the output and the amount (percentage) of clipping. So, this control is called the "fuzz-tone" control. At the output, another control, R7, sets the output signal level. From the output jack, the signal is fed directly into the input of the guitar amplifier. Switch S1 allows the fuzz tone to be switched in or out, at will. As you can see, in the "out" position, the signal goes straight through the unit to the output jack. In the "in" position, it goes through the fuzz circuitry.

With only two small transistors, and a very small power output, these units are powered by a 9-volt transistor radio battery. Some of them have clips inside the case, for holding a spare battery, in case it goes out during a performance.

Testing these is easy; just turn the switch on, set the fuzz control to maximum, and play a few chords. You'll be able to hear the fuzz effect if it's working. If no signal will go through the unit, check the battery voltage first; if this is up to normal, then check the input and output jacks, wiring, switch, etc., to make sure that the "signal-path" is not open. If these



(A) Input signal waveform.

(B) Output signal waveform.

Fig. 2-21. Input and output signals of a "fuzz-box."

are all in good shape, one of the transistors may be bad. Checking these can be done with the same tests and equipment used for any other amplifier, for that's all it is—a two-stage transistor amplifier.

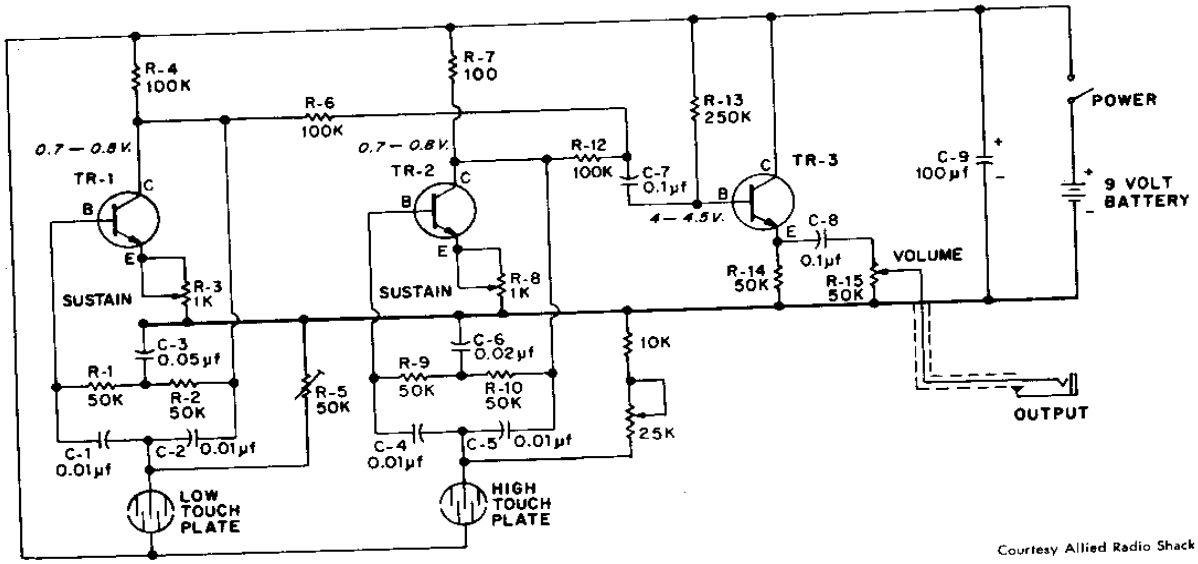
The Electronic Bongos

Another interesting special-effects device is actually an "electronic drum"; in fact, it is called the "electronic bongos." Fig. 2-22 shows the schematic diagram of this unit. Electronically, it's fairly simple. There are two pulse generators controlled by capacitive "touch-plate" switches. These are special capacitors used to trigger electronic circuitry; you've probably seen them used for "push buttons" (which didn't push) on automatic elevators.

Each unit has two of these, like the original bongo drums, which are played in pairs, one tuned to a high pitch and the other to a lower. Note that one is marked "low" and the other "high." Each of these is actually a triggered *oscillator*. They are set up so that the circuit is *not* oscillating, but is ready to, at even the slightest disturbance. This disturbance is provided by touching the touch-plate switches. This starts the oscillator to working, and it gradually dies away and stops.

This generates a very sharp, short "pulse-train" signal, which, fed to an amplifier, creates a sound exactly like the hollow ringing sound of a real bongo drum. The length of this pulse-train can be controlled by the "Sustain" control in each circuit; R-5 in the low and R-11 in the high. The output of both bongo circuits is fed to an output amplifier, TR-3, and then to the amplifier, through the output jack and cable. This can be fed into one of the low-gain inputs, since the output is at a fairly high level, much greater than the output of a microphone or guitar pickup.

Testing these units is not difficult. If the unit doesn't work at all, check the battery voltage. If this is up to normal, check the output amplifier stage by feeding a signal into its base. A bad transistor, open



Courtesy Allied Radio Shack

Fig. 2-22. Schematic diagram of an electronic bongo.

coupling capacitors C-7 or C-9, or open wiring, can kill the output.

The bongo oscillators can be very easily checked by running the "setup" tests to make sure that they can oscillate. Turn the volume control full on, then move the setup control, R-5, for the low, or R-11 for the high. Move this just a very little bit. If the oscillator is working, you'll hear the amplifier begin to squeal. This should start at a very low pitch, and gradually go higher as the control is turned. If you hear this reaction, this oscillator is alright. Check the touch-plate wiring; touch the contact with the tip of a screwdriver, test prod, etc. If the oscillator circuitry is alright, this should make the oscillator work, and you'll hear the hollow "bong" in the speaker.

If the control works, reset it to the correct place. Turn it so that the squeal goes *down* in pitch and then stops. Check by touching the touch-plate. Do not set this control so that the squeal goes up in pitch and then stops; this is wrong, and the bongo won't work.

If one bongo works but the other does not, you can cross-check between the dead one and the working circuit for dc voltages, resistance, etc. Parts values are very close to the same, aside from the frequency-determining capacitors. Look for things like leaky capacitors, leaky or shorted transistors, or open wiring. Fig. 2-23 shows how the touch-plate switch unit is assembled to make the "bongo" unit on the cabinet.

Electronic Drummer

Now, we come to a class of units which I must admit makes me just a bit resentful; they're of the type where "machines replace people." These are special-effects devices which can be plugged into the main amplifier, and will generate any kind of rhythm beats—they replace the drummer.

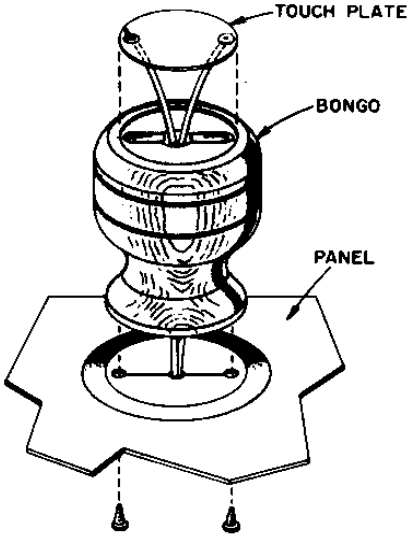


Fig. 2-23. Touch-plate capacitive switch used in the bongo.

These amazing devices are actually signal generators. By the use of pulse-generating circuitry of the same type as that used in computers, they can give very realistic imitations of the sounds of a bass drum, snare drum, and a "top-hat" type cymbal. The speed (tempo) of the beats can be set wherever necessary. In addition, they can be switched to provide the typical background rhythms of any kind of music. Anything from what we used to call a simple "boom-trot" (march or 2/4) rhythm to a syncopated rock beat can be obtained.

Fig. 2-24 shows a complete schematic diagram of one of these units, a Knight-Kit KG-392 "Combo Sideman." This unit works by generating pulses. For example, the hollow boom of the bass drum is generated by a very low-frequency (phase-shift) oscillator shown at the upper left corner of the schematic. This oscillator has a pitch adjustment and a sustain control to allow the musician to select either the full-toned boom or the shorter "thud" sound of a muffled bass drum. The characteristic sound of a snare drum is made by keying in very short bursts of "white noise," which is basically a blow or rushing sound. Another circuit generates the bell-like tone of the cymbal, once again keyed in bursts on the beat.

By adjustment of the Rhythm Control, the bass drum can be made to sound on the down-beat, with the snare drum and cymbal on the up-beat, or on the after-beat, depending on the type of rhythm desired. For syncopated beats, any of the "instruments" can be "accented" (made louder). For solos by the lead or melody instrument, where the drummer usually lays out (stops), pressing the "Solo" button will make the device play a straight or unaccented series of beats, such as bass drum alone as background.

Testing and Repairing

The "electronics" in this unit are all on a single PC board, which is wired to the controls through cables. The basis of the variable-tempo and rhythm circuitry is a group of flip-flops, seen at the lower left of the schematic (Fig. 2-24). Although integrated circuits may be used in future models, the flip-flops in this unit are "discrete components," and so can be tested and repaired individually if need be.

Once again, the fastest test method is the process of elimination. Check the unit; if none of the sections is working, check the battery or power supply first. Nothing can work without the proper voltages. After making sure that voltages are within limits, check the

NOTE:Pages32-33containedschematicforKnight/RadioShack"ComboSideman"Rhythm machine.Schematicwastoodetailedforscanner,andoriginalofpoorquality.

unit to find out just which sound effect isn't there. Always check interconnecting cables, switches, and the rest of the simple things before suspecting any serious trouble in the electronics. Because of the hard wear that cables get, they can cause a lot of the troubles.

If, for example, the bass-drum sound is missing, but the snare and cymbal come through, go straight to the bass-drum oscillator circuit, shown in the upper left of the schematic. This circuit is basically a low-frequency phase-shift oscillator, of the same type used for vibrato in other amplifiers. Any of the capacitors or resistors being off-value, either open or shorted, can kill the oscillator or make it run far off the correct frequency. Check the oscillator transistor for open or shorts, and check all resistors and capacitors for proper value, leakage, or drift. Note that there are quite a few diodes used as *couplers* in this unit. If any one function fails but the basic oscillator seems to be working, check the coupling diodes for either open or shorts. (Diodes also work as "shapers" in some of the wave-forming networks.)

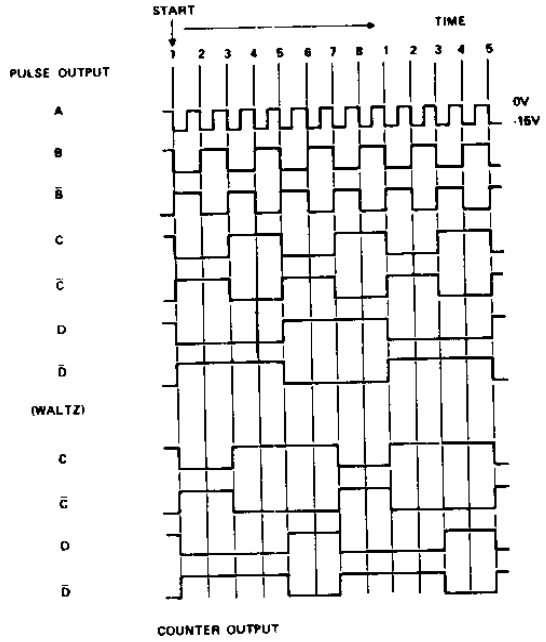
In this type of circuitry, the scope will be by far the most helpful test instrument. The output waveforms of each stage are shown on the schematic. The scope will tell you instantly and definitely whether a given stage is working or not. You can also use it to follow the different signals through the coupling and shaping circuits to the output.

Rhythm Console

Fig. 2-25 shows the schematic of a much more elaborate unit of this type. This is the Knight-Kit "Rhythm Console," and is basically like the unit we just looked at. However, this unit has a total of *ten different* rhythms—waltz, tango, bossa nova, cha-cha, beguine, mambo, rumba, slow rock, twist and swing. Any of these can be selected by a push-button switch on the front panel. It can produce the sounds of *eight* different percussion instruments: bass and snare drums, two bongos (high and low), claves, maracas, cymbal, and even a cow bell.

Computer circuitry is used even more extensively here than in the previous unit. The basis of the sounds is once again a group of phase-shift oscillators, set so that each one is right on the verge of going into oscillation, like in the electronic bongos. These oscillators are triggered on by a keying pulse; this pulse comes from a unit which has four astable multivibrators, plus a countdown circuit for forming the desired rhythm. The pulses are fed through buffer amplifiers, differentiating circuits, and gating circuits to control both the output and frequency of the oscillators. The combined output of the oscillators is then mixed and fed through an output amplifier. The output of this amplifier goes to a low-level input jack on the main amplifier.

Servicing and testing methods are just the same as those used for the preceding unit. Counters, oscillators, gates, etc., can be easily checked for proper output with the oscilloscope. Fig. 2-26 shows the normal counter output waveforms. Fig. 2-27 shows the waveforms at the AND gate, Fig. 2-28 shows the differentiator output, and Fig. 2-29 shows the output of the OR gate.



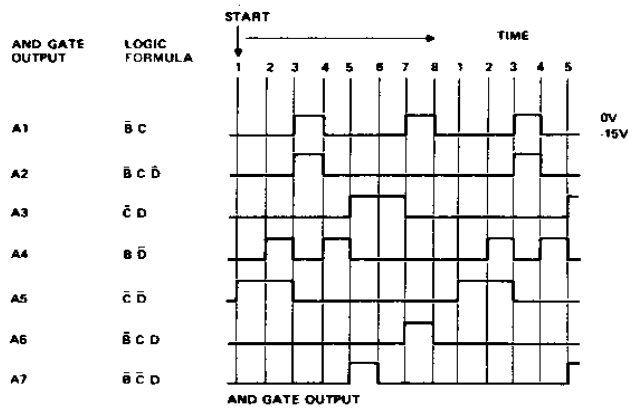
Courtesy Allied Radio Shack

Fig. 2-26. Normal counter output waveforms.

Once again, the counters, etc., are discrete component types, so that they can be repaired if a part fails. This, too, will undoubtedly be "out" in an IC version, possibly before this book is printed. However, servicing will still be the same. If any stage does not have the normal output, all external parts are in good shape, and correct voltages being supplied, etc., then you replace the IC.

Maestro Rhythm 'N Sound for Guitar, Model G-2

Another interesting special effects device is the Maestro Rhythm 'N Sound for Guitars. The schematic for this unit is shown in Fig. 2-30. This unit is a completely transistorized sound modification device de-



Courtesy Allied Radio Shack

Fig. 2-27. AND gate output waveforms.

signed to be used with a guitar and amplifier. The circuit operation follows.

Input Preamp No. 1—Transistor Q1 amplifies all input signals from the guitar except those sent to Fuzz Preamp 1, Q18. The No. 1 Input Preamp's output is directly connected to the Input Preamp No. 2, Q2, and through the Natural Amp tabswitch to Percussion Modulator Q22. In addition, when the Echo Repeat, Wow Wow, and Color Tones 1 or 2 tabswitches are off, the output signal from Preamp 1 connects to Output Preamp Q29.

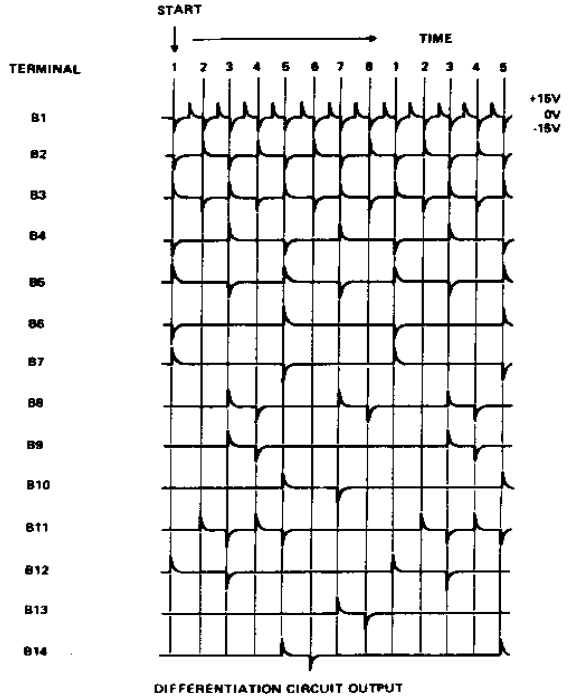
Input Preamp No. 2—Transistor Q2 provides a second stage of amplification for the previously amplified guitar signal from Preamp No. 1. This output signal is applied to Pick Detector Preamp Q3, provided one or more of the following tabswitches are in the on position: Wow Wow, Echo Repeat, Brush, Clave, Tambourine, Bongo and String Bass. When the String Bass tabswitch is in the on position, the signal from Input Preamp No. 2 Q2 is also connected to Squaring Preamp Q8.

Pick Detector Preamp—Transistor Q3 provides further amplification of the previously amplified guitar signal from Input Preamp No. 2 Q2 through the Sensitivity Control VR1. By properly adjusting the Sensitivity Control, this circuit amplifies only the strong guitar signal which is produced when a string is initially "picked." The output signal from this preamp is connected to Pick Detector Q4.

Pick Detector—The signal from Pick Detector Preamp Q3 is converted (rectified) by Q4 to a positive voltage pulse suitable for triggering the One-Shot Multivibrator Q5-Q6. Since the positive voltage pulse is capacitively coupled, only rapid voltage changes will be sensed by the One-Shot Multivibrator.

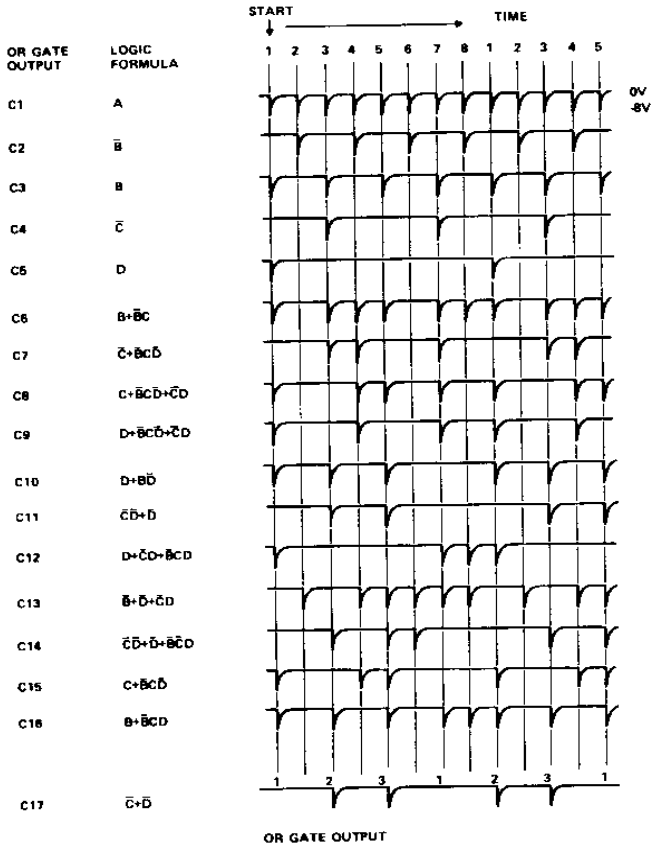
One-Shot Multivibrator—When Q5-Q6 is triggered by a positive pulse from Pick Detector Q4, this circuit momentarily grounds the capacitor connected to the base of Pulse Former Q7 and, when the Wow Wow tabswitch is on, the base of the Wow Wow Shaper Amp Q25 through diode D8.

Pulse Former—A strong positive voltage pulse is produced at the collector of Q7 when its base is grounded through a capacitor by the One-Shot Multivibrator Q5-Q6. The voltage pulse from the Pulse



Courtesy Allied Radio Shack

Fig. 2-28. Differentiation circuit output waveforms.



Courtesy Allied Radio Shack

Fig. 2-29. OR gate output waveforms.

Former is used to key the circuits listed below providing their respective tabswitches are in the on position:

Noise Amp Q 15 (Brush)
Noise Gate Q16 (Brush)
Tambourine and Clave Generator
Bongo Generator Q17 (Bongo)

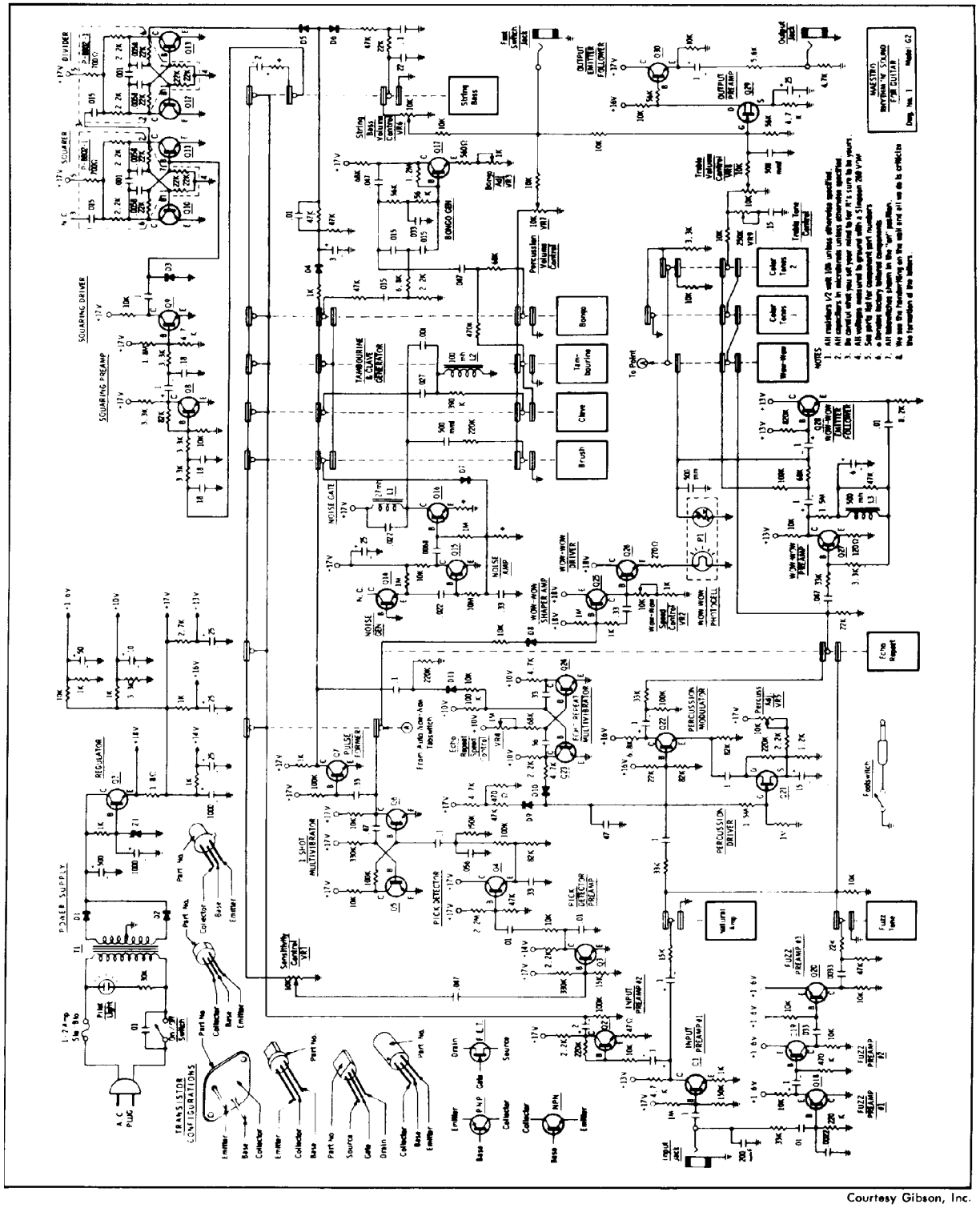
In addition to these circuits, the pulse from the Pulse Former is used to key through diode D4, diodes D5 and D6 which are in series with the output from Divider Q12-Q13. Also, the Pulse Former output pulse is used to trigger (through diode D11) the Echo Repeat Multivibrator Q23-Q24, causing it to restart with the pick of the guitar string.

Squaring Preamp—The amplified guitar signal from Input Preamp No. 2 Q2 is RC filtered to produce a square waveform signal, and then amplified by Q8. The output of Squaring Preamp Q8 is connected to Squaring Driver Q9.

Squaring Driver—The filtered and amplified guitar signal from Squaring Preamp Q8 is further amplified and clipped (diode D3) to provide a square waveform drive signal for Squarer Q10-Q11.

Squarer—The amplified and clipped guitar signal from Squaring Driver Q9 is converted to a square-edged waveform signal. This square-edged signal is used to drive Divider Q12-Q13.

Divider—The square-edged signal from Squarer Q10-Q11 is divided down by Q12-Q13 to a square waveform signal of half the input frequency. Example: A 440-hertz squared signal becomes a 220-hertz square waveform signal. The output signal from the Divider is connected to a diode keying circuit (diodes D5 and D6) which is keyed by the positive voltage pulse from Pulse Former Q7 through diode D4. The output of the Divider circuit then connects to the String Bass tabswitch, String Bass Volume Control VR6, and on to Output Preamp Q29.



Courtesy Gibson, Inc.

Fig. 2-30. Schematic diagram of the Maestro "Rhythm 'N Sound for Guitar," Model G-2.

Noise Generator—A constant B+ voltage applied to the emitter of transistor Q14 causes the internal base-emitter junction to zener breakdown, thus producing a constant random noise signal. The output of the Noise Generator is connected to Noise Amp Q15.

Noise Amp—When not keyed, Q15 acts as a blocking circuit between Noise Generator Q14 and Noise Gate circuit Q16. Two things happen to the Noise Amp circuit when it is keyed by a positive voltage pulse from the Pulse Former Q7 through diode D7:

1. It amplifies the noise signal from Noise Generator Q14. (A positive voltage applied to the base of the Noise Amp biases it "on.")
2. The amplified noise signal is allowed to pass to Noise Gate Q16.

Noise Gate—The noise signal from Noise Amp Q15 is amplified and voiced when Noise Gate Q16 is momentarily biased on by a positive voltage pulse from Pulse Former Q7. Output signal from the Noise Gate is connected to the Brush tabswitch and Tambourine circuit L2.

Bongo Generation—Q17 is a low-frequency oscillator that produces a short duration audio signal of diminishing amplitude when excited by a positive voltage pulse from the Pulse Former Q7. The output of the Bongo Generator is connected through the Bongo tabswitch and Percussion Volume Control VR7 to Output Preamp Q29.

L2 Clave and Tambourine Generator—A positive voltage pulse from Pulse Former Q7 excites the Clave Generator (mainly coil L2 and capacitors) into momentary oscillation. The Clave Generator output signal is connected to the Clave tabswitch. When the Tambourine tabswitch is on, the Clave circuit is combined with Brush signal to produce the Tambourine signal.

Fuzz Preamps—These three preamps, Q18, Q19, and Q20, amplify and clip the input signal from the guitar. The output signal is obtained from the third Fuzz Preamp. (The output is like the original input waveform except the waveform peaks are clipped.) The output from Fuzz Preamp No. 3 connects through the Fuzz Tone tabswitch to Percussion Modulator Q22, or through the Echo Repeat tabswitch to Wow Wow Preamp Q27 and Output Preamp Q29 when the Wow Wow and Color Tone tabswitches are off.

Percussion Driver—Positive voltage pulses from the Echo Repeat Multivibrator Q23-Q24 are converted into highly linear momentary drain-to-source resistance changes by Q21. These resistance changes effectively ground the emitter element of Percussion Modulator Q22.

Percussion Modulator—The audio signal from Input Preamp No. 1 Q1 and/or Fuzz Preamp No. 3 Q20 is applied to the base of Q22. When Q22 emitter element is momentarily grounded by Percussion Driver Q21, a short pulse of audio signal is allowed to pass. This audio pulse is applied through the Echo Repeat tabswitch to Wow Wow Preamp Q27 and to Output Preamp Q29 when the Wow Wow and Color Tone tabswitches are off.

Echo Repeat Multivibrator—This multivibrator, Q23-Q24, runs continuously except when restarted by a pulse from Pulse Former Q7 through diode D11. The multivibrator runs at the speed set by Repeat Speed Control VR4. As this circuit runs it produces strong positive voltage output pulses that are connected through the diode D10 to the Percussion Driver Q21.

Wow Wow Shaper Amp—When the base element of Q25 is momentarily grounded through diode D8 by One-Shot Multivibrator Q5-Q6, a positive voltage pulse is developed at the collector. This output pulse is connected directly to Wow Wow Driver Q26.

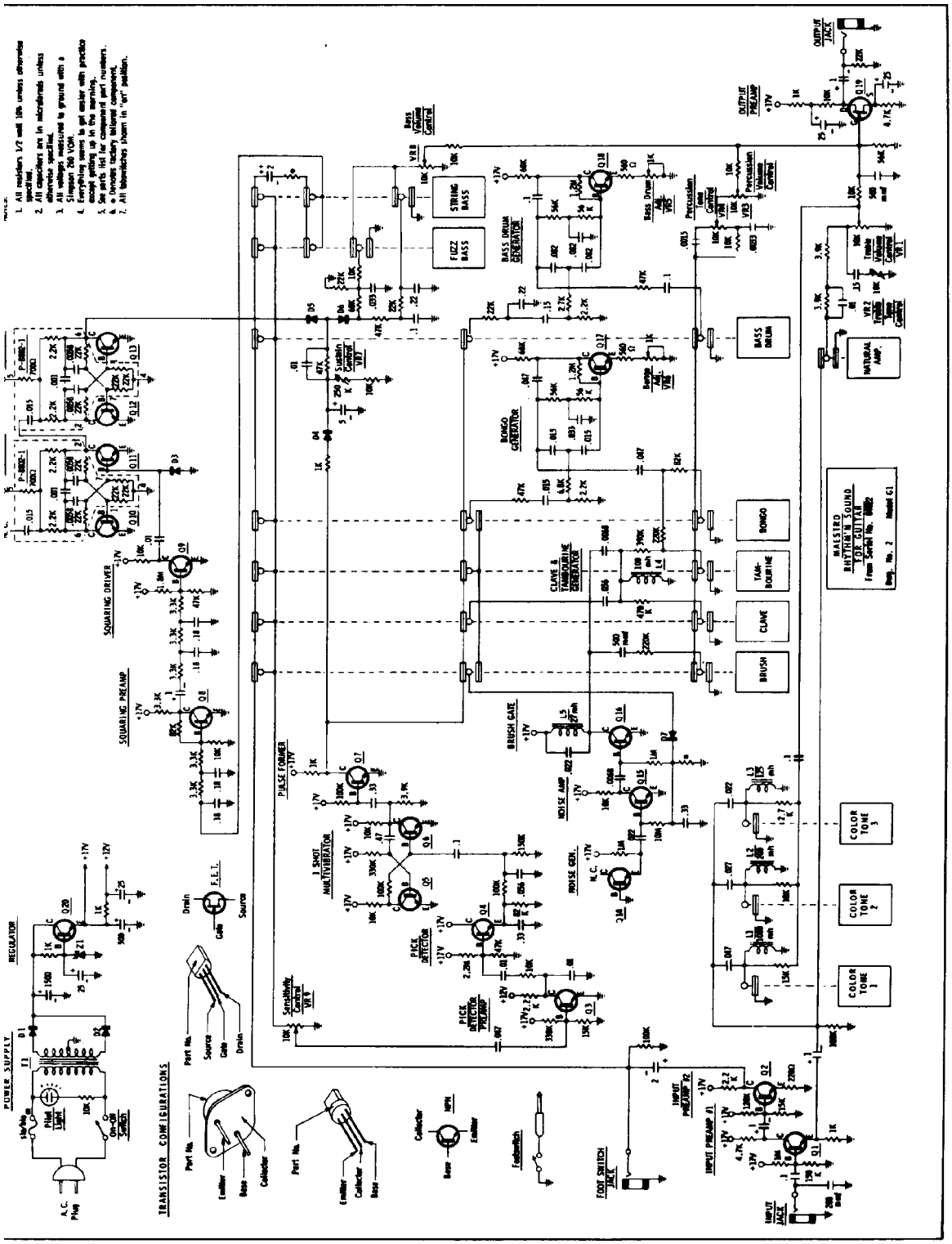
Wow Wow Preamp and Emitter Follower—The audio signal from Input Preamp Q1, Fuzz Preamp Q20, or Percussion Modulator Q22 is applied to this preamp. Wow Wow Preamp Q27 is a variable tuned circuit that amplifies only the audio signal near the frequency to which it is tuned. This frequency range is approximately 300 to 1700 Hz. The Wow Wow Photocell P1, together with the Emitter Follower Q28, determines the frequency to which the Wow Wow Preamp is tuned by electrically changing the effective value of the .01-μF capacitor attached to the emitter of this transistor.

Output Preamp and Emitter Follower—All Percussion, Bass, Natural Amp, Fuzztone, Wow Wow and Color Tone signals are combined and amplified by these two circuits, Q29 and Q30. The output signal from Emitter Follower Q30 connects to the Output Jack and on to a suitable power amplifier.

Regulator—Transistor Q31 works in conjunction with zener diode Z1 to regulate and filter the dc voltage produced by power transformer T1, diodes D1 and D2, plus several resistors and filter capacitors.

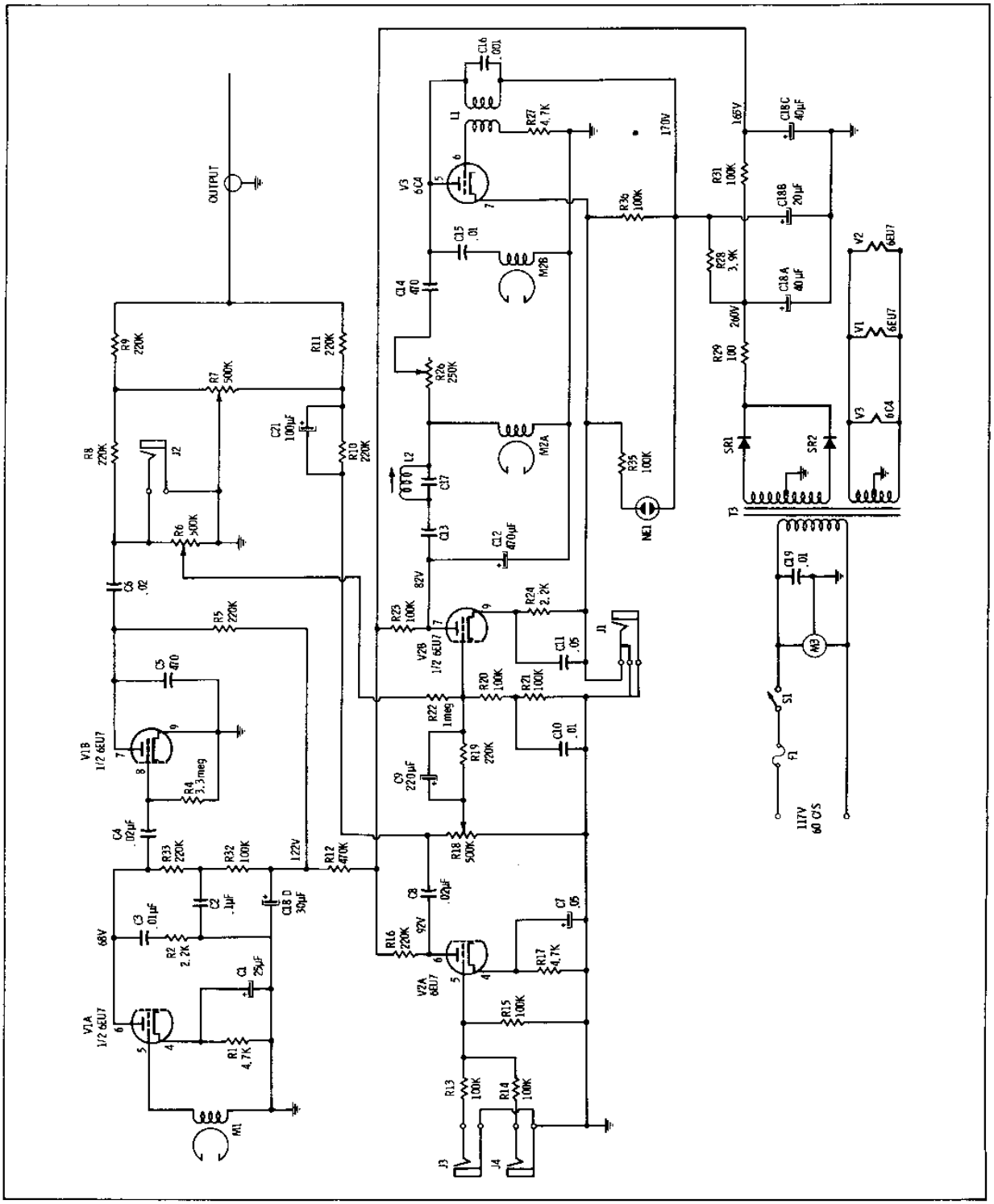
Maestro Rhythm 'N Sound for Guitar, Model G-1

This is another special effects unit designed to be used with an amplifier and guitar. Special effects sounds that can be created with this unit are bass drum, bongo, brush tambourine, clave, string bass, and fuzz bass. Circuit operation is very similar to the Model G-2 previously discussed. The schematic diagram is given in Fig. 2-31.



Courtesy Gibson, Inc.

Fig. 2-31. Schematic diagram of the Maestro "Rhythm 'N Sound for Guitar," Model G-1.



Courtesy Market Electronics Co.

Fig. 2-32. Schematic of Echoplex tape unit.

Echoplex Tape Unit

Another very interesting special effects unit, the Echoplex can be used with a guitar or other musical instrument. Its purpose is to create an "echo" sound along with a straight through guitar sound. It is an interesting unit, since it uses no mechanical springs to effect the delay.

The unit is provided with a movable magnetic head that enables it to match beat and rhythm. It is designed to provide simultaneous recording and playback, which introduces the necessary delayed signal for the echo. The desired number of echo repeats is set with the Echo Repeats Control. The Sliding Head Pointer is used to obtain the desired echo delay. A schematic of the unit is shown in Fig. 2-32.

The Power Supply

The power supply has deliberately been left until the last because it is the most important part of any amplifier. It is also the source of about 90% of the troubles you will find. Why is this? It is the part of the circuit that works the hardest—its components work under a greater voltage strain than any others, with the possible exception of the power tubes. (As a sidelight, be sure you are not confused by the following. A power tube in an amplifier is the output tube—part of the power amplifier. The rectifier tube in the power supply is the one that supplies the operating power to all the tubes. So, if power tubes are mentioned, look in the power amplifier; if the power supply is referred to, look for rectifiers.)

Parts will break down under load—resistors will burn up and capacitors dry out or change value. Then you have problems. Hum, noise, oscillation, and many other troubles have their origin in power-supply voltages—from insufficient filtering, incorrect voltage values, and so on. Ways of finding and fixing all of this will be dealt with in detail in the section on servicing. At this point, here are brief descriptions of the different types of power supplies you will find in commercial amplifiers.

THE AC/DC POWER SUPPLY

The simplest is the ac/dc power supply, found only in very low-powered amplifiers with an output up to about 2 watts (audio). Fig. 3-1 shows a typical ac/dc power supply circuit using a vacuum-tube rectifier. Typical tubes used in this circuit have type numbers beginning with 35 (35W4, 35F5, etc.), indicating their filaments are designed to operate at approximately 35 volts. The ac line (117 volts is standard) is connected directly to the plate of the rectifier tube, where it is rectified to pulsating dc by the tube, then filtered to a fairly smooth dc in the filter circuits. Resistor R2, capacitor C1, and capacitor C2 make up what is called a pi-type filter; its schematic resembles the Greek letter π. In the better circuits, filter resistor R2 is replaced by a small iron-core choke. The choke gives much better filtering action, but the resistor is cheaper. Most of the actual filtering in this circuit is done by large electrolytic capacitors C1 and C2 that are usually 80 to 100 microfarads at 150 working volts.

In these circuits the tube heaters, or filaments, (either word is correct) are simply connected in series. This is possible because they all will have been designed for the same filament current. The total voltages must add up to the line voltage, 117 volts. In the circuit shown in Fig. 3-1, for example, the tubes could be a 35W4, 50L6, a 12SQ7, and two 12SK7's. This would give a total of 121 volts, but this is common; designers usually leave a small margin of safety in the voltages to take care of line surges, etc. Any combination of tubes that adds up to the right line voltage can be used; if the total comes out short, a series resistor is added to take up the extra voltage. These tubes are usually operated at about 5% below their rated voltage for longer life.

This type of power supply is called ac/dc, because it will work just as well on 117-volt dc as it will on the more common ac. Of course, the applied dc must be of proper polarity so it can flow through the rectifier to supply plate voltages (B+). Due to the fact that one side of the circuit is connected directly to the ac line, there is always a shock hazard present when this circuit is used. If you do have one of these to work on,

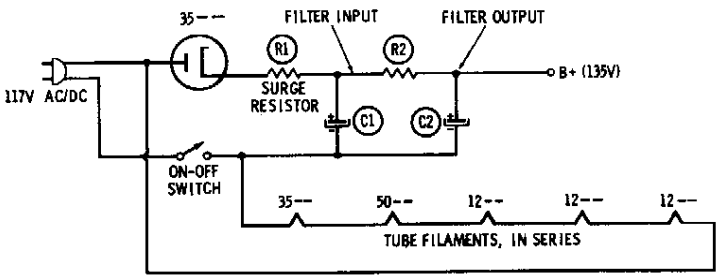


Fig. 3-1. An ac/dc power-supply circuit.

be very careful not to touch the chassis unless you are standing on a dry, well-insulated surface. Incidentally, a concrete floor is not an insulator—it is a well-grounded conductor.

You may have noticed that the output voltage seems to be higher than the input: 135 volts on the simple half-wave rectifier with 117-volt line input. This variation is due to the method of measurement used for the ac voltages. See Fig. 3-2. Dc voltage is straight, but when measuring ac voltages, one normally reads the rms value. In the operation of rectifier circuits, the filter capacitors are actually charged up to the peak value of the voltage. This is 1.414 times the rms voltage. The load on the B+ will pull this down slightly, but the output will still be higher than the numerical value (rms) of the input. This is normal, and it is just a trick of measurement and definitions.

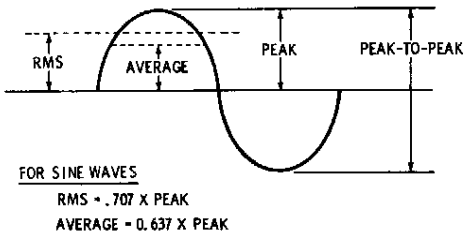


Fig. 3-2. Measuring alternating voltages.

DRY RECTIFIERS

In many sets today you will find a silicon or a selenium rectifier instead of a vacuum tube. These so-called dry rectifiers (semiconductor diodes) do not require any filament voltage, thus saving that much power. Also, their life is much longer than the vacuum-tube rectifiers that are prone to sudden failure if there is a short in the amplifier itself. Fig. 3-3 shows a typical power-supply circuit using a dry rectifier. Note that the dc output is higher than for the comparable tube circuit since this rectifier is more efficient.

The schematic symbol used is the same for both the older selenium rectifiers and the new silicon types. The triangle is the plate or anode of the rectifier, and the crossbar is the cathode. In this circuit the triangle (anode) is always connected to the source of ac voltage, and the B+ comes from the crossbar (cathode).

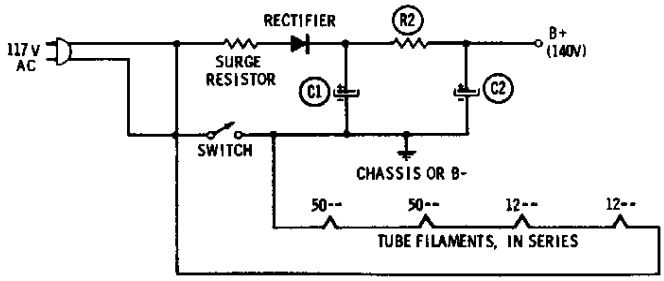
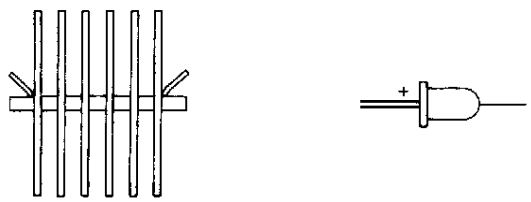


Fig. 3-3. Dry rectifier power supply.

Fig. 3-4 shows the two rectifiers: the selenium types have the large cooling fins, while the silicon are much smaller and more compact. Silicon rectifiers are available in many different sizes and shapes other than the one shown. Voltage drop across the silicon types is much smaller than even the seleniums, and the former have replaced the latter in modern designs. Incidentally, you can use either one interchangeably, providing the current rating of the replacement rectifier is equal to or higher than that of the bad one you are replacing.

The PIV (peak inverse voltage) or breakdown rating of the rectifier must be at least 20% greater than the applied voltage. For safety, the current rating must be at least 25% higher than the peak current to be drawn by the amplifier. The safety factor can be greater than this; these are minimum figures. Rectifiers with a good safety factor will last much longer in service.

Note the little resistor shown in the schematics, between the rectifiers and the ac line. This is small, usually 8 to 15 ohms and is used to hold down the first inrush of current; therefore it is called a surge resistor. Since the dry rectifiers do not have to warm up, they conduct full current as soon as the set is



(A) Selenium. *(B) Silicon.*

Fig. 3-4. Selenium and silicon rectifiers.

turned on. To keep this full current from damaging something, a small limiting resistor is included in the circuit.

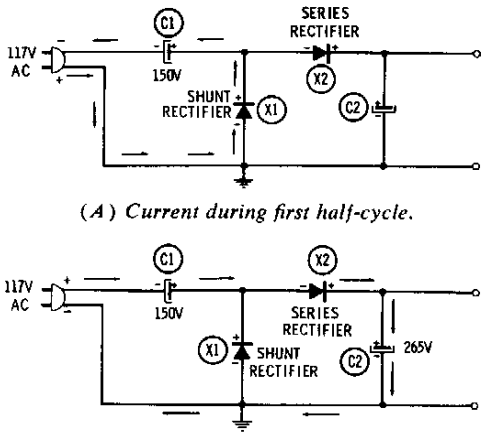
VOLTAGE DOUBLERS

With semiconductor rectifiers it is possible to build a type of circuit that will give more than double the amount of the standard line voltage. One of the drawbacks of ac/dc or line-rectifier circuits has been the low B+ voltage available—usually about 135 volts dc. With a circuit like that shown in Fig. 3-5, the B+ output can be double the line voltage.

The half-wave doubler power supply works as follows: Capacitor C1 is apparently connected directly to the ac line, despite all you have been told about electrolytics not working on ac. Actually, because of the circuits following it, the capacitor is not on the ac line. On the first half-cycle of the supply voltage, current flows through shunt rectifier X1, because its plate (anode) is positive (Fig. 3-5A); this charges C1 to approximately the peak line voltage minus the drop across the rectifier. On the next half-cycle (Fig. 3-5B) the polarity is reversed, and series rectifier X2 carries the current. The line voltage is now in series with the charge on capacitor C1, so capacitor C2 charges to approximately the sum of these voltages. Allowing for losses in the circuit and the slight discharging of the capacitors, the output is about 265 volts dc. Effectively, the line voltage has been doubled and rectified at the same time.

The two electrolytic capacitors are the key to this doubling action; it is their charging and discharging that make the circuit work. This holds true in all voltage-doubling circuits. All parts must be in good shape, of course, especially the rectifiers, but it is the charge/discharge cycle of these big capacitors that does the trick. C1 will be about 150 to 200 μF at 200 working volts, and C2 will be from 120 to 150 μF and must have at least a 300 working-volt rating.

Incidentally, this is the circuit that stopped the ac/dc designation, although many diehard service technicians still call them that. The ac line is rectified



(A) Current during first half-cycle.

(B) Current during second half-cycle.

Fig. 3-5. Half-wave voltage-doubler circuit.

for B+, and the tube filaments are in series, but this is not an ac/dc circuit at all; it won't work on dc. You must have alternating current to make the voltage doubler function. If this half-wave doubler were connected to the wrong polarity of dc voltage, components could be damaged. The correct name for this circuit, and all others like it, is transformerless.

TRANSFORMER POWER SUPPLIES

The power-supply circuit used in most guitar amplifiers is the full-wave rectifier with power transformer. Fig. 3-6 shows a typical circuit. It works like this: The line voltage is stepped up in the high-voltage secondary winding to any desired value. In the average medium-power amplifier this is about 350 volts ac, so the output is about 300 volts dc after taking off the filter and rectifier-tube voltage drops. The other tube filaments are all connected in parallel and supplied from a filament winding as shown.

The rectifier tube is a full-wave type. Both halves of the ac wave are rectified as first one plate and then the other goes positive. This produces a small 120-Hz ripple in the rectifier output in addition to the dc voltage. This ripple is just a little bit easier to filter out than the 60-Hz ripple that results in half-wave recti-

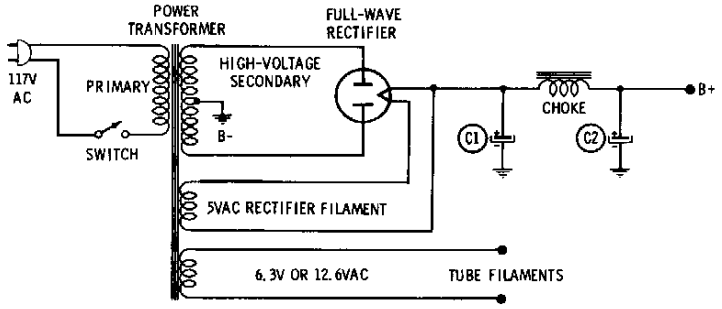


Fig. 3-6. Transformer power supply with full-wave rectifier.

fiers, so you will find much smaller filter capacitors in this circuit compared to the transformerless types. Filters will run about 60 to 80 μF instead of 125 to 150 or even 200 μF in the brute-force filters needed for the others.

The center-tap of the high-voltage winding is returned to the chassis, and this is used as B−. Filter chokes are generally used in place of resistors for better efficiency, and the dc output is usually very smooth. Normal ripple at the filter output is less than 2.0 volts pk-pk, which can be considered as almost pure dc.

This type of power supply has several advantages. For one, the power transformer provides complete isolation from the ac line, so there is no shock hazard. For another, the desired B+ voltage can be easily obtained by simply choosing a transformer with the desired step-up voltage ratio. Tube filaments are connected in parallel. If one burns out, it is easy to find since all the others remain lit. In series circuits, if one burns out, it opens the circuit and they all go out.

In some circuits you may find dry rectifiers used in place of the vacuum tube. These will sometimes be in a bridge arrangement as shown in Fig. 3-7. This circuit gives good rectification and simplifies the power transformer; no center tap is needed on the secondary. The output is slightly higher than when a tube is used.

In the larger amplifiers you will find two rectifier tubes. This is done to share the load between them, so the tubes will last longer. In the very high-powered amplifiers, two rectifier tubes will be used on the very high voltage for the plates of the power output tubes (up to 600 volts dc), and another will be used to supply the B+ to all other stages.

Formerly dry rectifiers were sometimes used in series to get a higher voltage breakdown rating. This caused some trouble, due to inequalities between the units. Now, you can get silicon rectifiers rated at 600, 800, and even 1000 volts, so there is no need for the series connection. These new units can be used to replace older series-stack rectifiers, with much reduced chances of failure.

Silicon rectifiers can also be used to replace rectifier tubes directly, to reduce the heat generated inside the amplifier case. Simply connect silicon rectifiers, with ample safety ratings, directly across the tube socket. For a full-wave rectifier tube, such as the 5U4, and others, two rectifiers are needed. Tie the cathodes to the original filament (or cathode, if the tube had a separate cathode), and tie one anode to each of the original plate pins. When making a conversion like this, you may have to add a small series surge resistor. Your dc voltage output will be quite a bit greater. This is due to the lower voltage drop across the silicon rectifier, as compared to that across the tube. Always check the dc voltage to make sure that it does not exceed the original voltage; filter capacitors and other parts may be overloaded and break down.

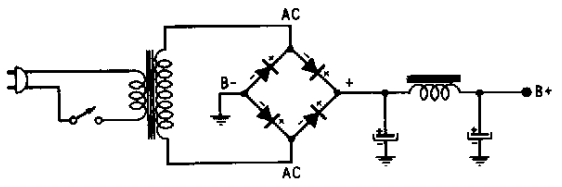


Fig. 3-7. Four dry rectifiers connected in a full-wave bridge circuit.

SPECIAL BIAS SUPPLY

A fixed-bias voltage is used for the power output stage in some of the larger amplifiers (Fig. 3-8). Follow the control grid circuits of the output tubes. They do not return to ground, as in the smaller units, but go through 1500-ohm swamper resistors (to damp out any tendency to ultrasonic oscillation) and 200,000-ohm grid resistors to a special negative voltage supply. This is provided by a 50-volt tap on the high-voltage secondary of the power transformer (T1). The ac is rectified by diode D1 and filtered by the 5600-ohm series resistor, the 100-μF electrolytic capacitor, and the 56,000-ohm loading resistor across the output of the bias rectifier. Notice that the output voltage of this circuit is negative: it comes from the triangle side of the dry rectifier instead of from the bar side as in the normal B+ circuits. Bias voltage varies with the type of tubes used and their bias requirements; it is usually around −50 volts in most of the high power amplifier circuits. This fixed bias is necessary to get 5881s and similar power tubes up to their rated output.

TRANSISTOR-AMPLIFIER POWER SUPPLIES

The power supplies used on transistor amplifiers will be exactly like the ones already shown. The same kind of transformer, rectifier, and filter circuits will be used. The only difference will be in the dc voltages and currents. Voltages will be much lower, ranging from about 15-20 volts up to perhaps 75-80 volts or more. Currents will be much higher, of course, to get the needed wattage (voltage times current).

The only new circuit you'll find will be in the transistor amplifiers using a dual-polarity dc supply for the output pair. Fig. 3-9 shows how this is done. The center-tap on the power-transformer secondary is grounded. A full-wave bridge rectifier is used, with

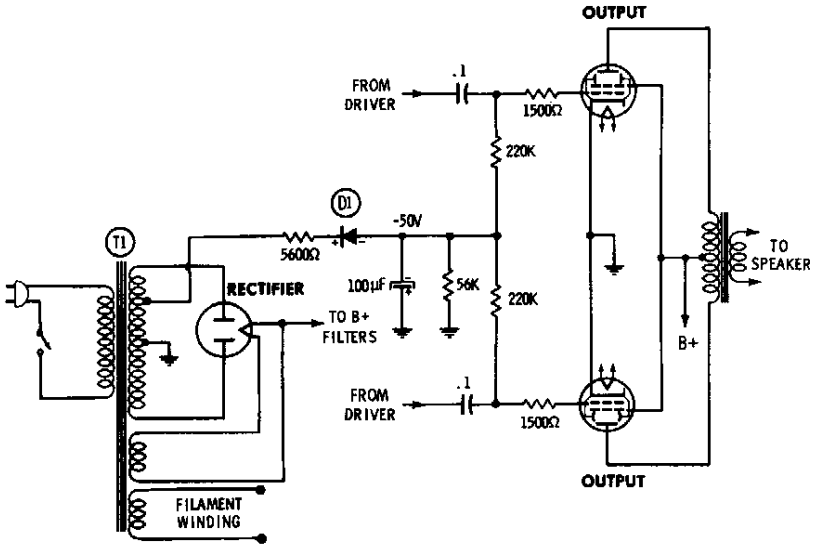


Fig. 3-8. Negative grid-bias voltage supply.

the negative voltage output taken from the minus (−) terminal, and the positive voltage from the plus (+) terminal. Duplicate filter circuits are used, with the polarity of the filter capacitors reversed.

The current rating of the transformer secondary winding and the rectifiers must be at least 25% greater than the maximum current to be drawn at full output. Voltage rating of the filter capacitors should be 25% higher than the maximum voltage; here, 50-volt capacitors should be used as a minimum. Filter capacitors will be much larger, often up to 1000 or even 2000 μF, and in some cases, filter capacitors up to 4000 μF have been used. Transistor circuits must have pure dc.

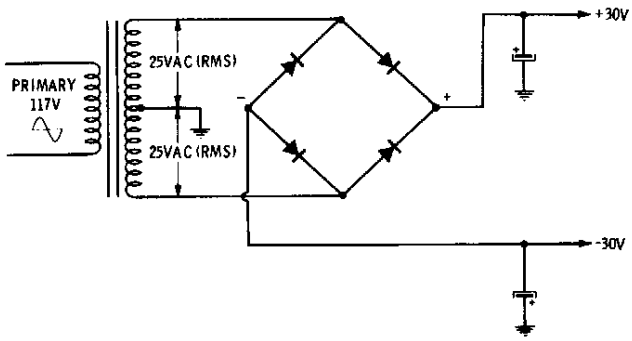


Fig. 3-9. Dual-polarity power supply.

SAFETY PRECAUTIONS—SHOCK HAZARDS

There is one thing which *must* be checked very carefully, whenever any ac-powered guitar amplifier is serviced. This is the *isolation* of the ac power line from the amplifier chassis. The "line-connected" power supplies, like those shown in Figs. 3-1, 3-3 and 3-5, may have one side of the ac line connected to the amplifier chassis. This is *not* a standard circuit, nor is it approved by the Underwriter's Laboratories, who set the standards for shock-safety in electrical equipment. However, by accident or design, it may be found in some of the cheaper models, so be on the lookout for it.

The reason for the danger is simple. One side of every ac power line is grounded; the other side is always "hot," with respect to *any grounded object*. In fact, you can light any incandescent lamp, by connecting one wire to the hot side of the ac line, and the other to a water pipe or other grounded object. In all musical instrument amplifiers, the amplifier chassis is a "common" which is connected to the shields of the cables, as well as the metal control-plates on the guitar itself, to avoid hum pickup. So, if the amplifier chassis is connected to the hot side of the ac line, the "grounded object" may be the *musician* himself, if he happens to be standing on bare earth, a cement floor, or touching water pipes or other grounds.

In this case, a dangerous, even fatal current can flow through his body. There has been one known instance of a musician being killed by a shorted amplifier, and unless we're very careful, there could be more! So, all ac-powered amplifiers should be checked carefully for deliberate or accidental shorts from the ac line to the chassis. Line-connected type amplifiers should *never* be used out-of-doors, or on a bare earth or cement floor, or near water-pipes, etc. However, these amplifiers are in the very low-powered class, and are not normally used for concert or dance work; they are used mostly by students and for indoor practicing. On wooden floors or insulated surfaces, they are safe.

The larger amplifiers are powered by power transformers, as in Fig. 3-6. Note that the primary of the

transformer is completely isolated from the secondary and the chassis of the amplifier. So, this type is completely safe, as long as there are no *accidental* short-circuits from the ac line to chassis.

Checking for Safety

There is a good quick-check for this. Whenever an amplifier has been serviced, and is working normally, connect a 1500-ohm, 10-watt resistor between the amplifier chassis and a ground. Connect an ac voltmeter across this resistor, as shown in Fig. 3-10. Now, plug the amplifier in and turn it on. There should be practically no voltage reading on the meter. If you read more than 2-3 volts ac on the meter, look out. If there is no voltage indicated, pull the amplifier ac line plug, reverse it, and plug it in again. If you get no ac voltage reading with the amplifier plugged in either way, the amplifier is safe to use. If you read even 10 volts ac with the plug in either position, there is too much leakage; reading the full line voltage indicates a dead short between ac line and amplifier chassis, and this is a potential killer!

In some amplifiers, a "line-reversing" switch is used to minimize hum (Fig. 3-11). This switching arrangement has the same effect as reversing the ac plug in the socket. In other circuits, you may find a large resistor, 2.2 megohms or so, bypassed with a small capacitor of about .05 μF connected from one side of

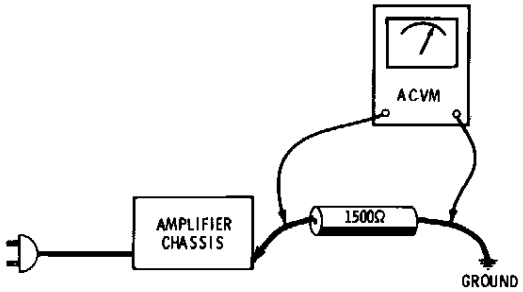


Fig. 3-10. Checking ac powered amplifier for a short to chassis.

the ac line to the chassis. This, too is for hum-reduction; the reversing switch is flipped so that this side of the ac line is grounded. Now the amplifier chassis is connected to the ground side of the line, and is safe.

If the amplifier has been plugged in at the time a nearby power line was hit by lightning, the "line bypass" capacitor may break down and short. Normally, this capacitor is shunted by the high resistance and only a very small current can flow. With a dead short in the capacitor, a dangerous potential can exist between the amplifier chassis and a ground. The quick-check will catch this hazardous condition. An ohmmeter test of the capacitor will confirm it. If this capacitor is replaced, be sure that the replacement has a rating of at least 1000 volts. This will make it harder to blow if the amplifier is hit again.

In very rare cases, a power transformer primary can short internally to the core. This has the same effect as a shorted line bypass capacitor. This kind of short can have no effect at all on the operation of the power transformer, except for the shock hazard. This, too, will show up on the quick-check test. You'll generally read about half of the full line voltage with the plug one way, and the rest with the plug reversed. For example, 40 volts one way and 70 volts the other; they will add up to the full 110-volt line voltage. Power transformers with this kind of defect MUST be replaced.

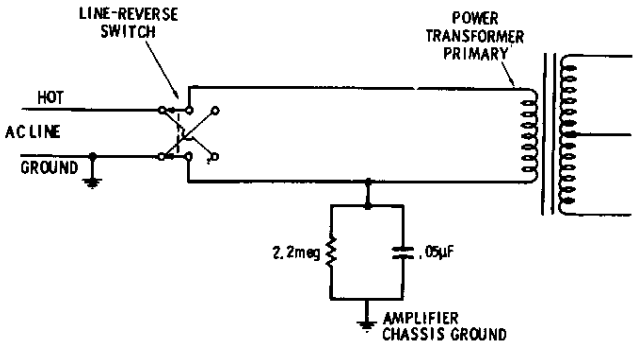


Fig. 3-11. Line-reversing switch and bypass capacitor circuit used to reduce hum.

SUMMARY

There you have a complete rundown on all of the circuits used in guitar amplifiers. If you know how each one works and what it is supposed to do, then it will be a lot easier to find and fix any trouble that shows up. In the next chapter professional methods of locating and curing trouble will be explained. Diagnosis is half the battle. Anybody can fix an amplifier; it takes only the replacement of a leaky capacitor or a burned resistor and two solder joints. The trouble comes in finding the correct part to replace. This separates the men from the boys, electronically speaking.

SECTION II

Service Procedures and Techniques

Chapter 4

The Amplifier Signal Circuits

The first thing to do in servicing an electric guitar amplifier is to look it over carefully. Find out what it isn't doing, and, just as important, find out what it is doing. As in all electronics work, the diagnosis is the hardest part. First, look for what is working; this will give you an idea as to what is not.

Troubles in amplifiers will fall into three classes; it will be dead, weak, or sound funny. This last class covers hum, oscillation, motorboating, and similar things; in other words, the amplifier is making the noises itself when it should not. The first thing to decide is in which class this trouble falls. Make the easiest possible test: turn the instrument on and listen to it.

A normal reaction in a functioning amplifier is a slight rushing sound in the speakers called "blow" (as if you were blowing very softly into a microphone). Some slight hum is also normal, especially if the input connections are open and the volume controls are turned up. All tubes should show a little light in the top, but none of them should get red hot or show any flashing between the elements. If you see the latter, turn off the amplifier immediately; there is a short somewhere in the power supply. Also, if you hear a loud hum, smell smoke, or see smoke coming from under the chassis, turn it off.

Take the easiest problem first—the completely dead amplifier. Nothing happens when you turn it on. This means that some part has completely broken down, and it is easy to find. Simply check out all circuits in the amplifier, beginning with the power supply. It doesn't take long to find a bad component with the proper tests. These tests are listed in later paragraphs.

First, look at the statistical order of failures in this kind of electronic equipment. The author's experience in actual repair operations indicates certain troubles are more likely than others. The experienced technician checks them in the order of frequency of occurrence, and he finds the trouble faster. Likelihood of failures come in this order:

1. Tubes
2. Power supply
3. Components—resistors, capacitors, and controls
4. Cables—plugs and wiring between the guitar and the amplifier
5. Transformers—output transformers, speakers and power transformers

Remember this list, and use it; it will make the repair job a lot faster. If you find a completely dead amplifier, the first thing to look for is a bad tube. The second most likely source of failure is something in the B+ power supply, and so on in the order given.

In checking electric guitars, break the complete system down into three parts—the amplifier itself (including the speakers), the connecting cables, and the guitar (including the pickup and controls on it). Here is how to check it out. First, pull out all cables to the instruments and mikes. Turn the amplifier on, and listen for any signs of trouble. See if you can hear the normal blow or hum that means it is alive. If you do not, check at any one of the inputs. Turn its volume control all the way up, and touch the hot terminal of the jack. If the amplifier is working, you ought to hear a very loud buzz or honk noise in the speaker. There are two easy ways to make this test: One, plug in one of the cables, and touch the tip of the phone plug; this is always connected to the hot terminal on the jack. Two, make up a special test plug with the hot wire brought out to where you can touch it with a

fingertip. Try this on an amplifier you know is working, and you will recognize the sound the next time you hear it.

If you hear a loud buzz, chances are the amplifier is all right, so go to the connecting cables. Plug them into the amplifier one at a time, and touch the center conductor of each cable. Again, the loud buzz says this section is functioning. Before going on, however, flex each of the cables near both connectors while touching the center conductor. Any static or break in the buzzing sound indicates there is a problem in the connector. Look over each one carefully for poorly soldered connections, broken wires, and strands of wire shorting across the connector. The section on servicing has procedures for repairing shielded cables.

When the connecting cables have been eliminated as the source of trouble, only the pickup remains. About all that can be done here is to substitute a new unit. If it is definitely established that the pickup is at fault, some effort can be made to repair it, and there are suggestions in the section on servicing as to how to proceed. Since these usually are sealed units, it is probably quickest to replace the pickup if replacements are readily available.

If you don't hear a loud buzz when you touch a hot input terminal, the amplifier is dead. Check to be sure that all volume controls are turned on in the channel you are testing. (In all servicing, you must watch out for the obvious; it is easy to overlook. For instance, if you are not careful, you may take the amplifier out of the case looking for a dead stage, and then find out that the master gain control had been turned off. Don't laugh—it has happened!)

If you can't get a sound through the amplifier from one input jack, try another one; try them all, in fact, before you pull the amplifier chassis out of the case. It may be that one channel is dead and the others are all right. If no sound is heard at all, pull the amplifier. More detailed testing will have to be performed.

Set the amplifier upside down on the bench, and make sure that the speaker is still connected. In high-powered amplifiers you can overload the output tubes and burn up a very expensive output transformer in about one minute if the amplifier is turned on without the right load (the speakers) connected. In some amplifiers you may have to rig up extension wires, but this is easy.

Transistor amplifiers are even more critical than the high-powered tube-types, on this point. There are two basic circuits used, the output transformer type and the transformerless type. Each has its own individual requirements. With the Class-A single-transistor type, do *not* turn the amplifier on with the speaker *open*. These will stand a short across the output, but operating the amplifier with the output open may blow the output transistor(s).

The output-transformerless types are exactly the opposite. They can withstand an open circuit in the output, but a short across the speaker terminals will blow both output transistors in a fraction of a second. When you hook up extension cables to the speakers or to a dummy load resistor, be very sure that there are no dangerously exposed bare wires, such as wires twisted together for extensions. Use only well-insulated test leads with insulated alligator clips, etc.

The reasons for this circuit peculiarity will be discussed in detail in the section on power-output testing.

CHECKOUT PROCEDURES

Here is a step-by-step method of testing that will show you where the trouble is in the least possible time. This is based on actual field experience in repairing these amplifiers, so follow it as closely as you can.

1. Check the B+ voltage—most of the troubles will be found in the power supply.
2. Check the amplifier, stage by stage, for voltage on plates and screen grids. Use a dc voltmeter for testing, set on a scale that is at least twice the maximum voltage you expect to find. For example, if there is about 250 to 300 volts of B+, then use a 500-volt scale to save damaging the meter.

When servicing, always start at the output—the speaker and output tubes—and work your way back toward the inputs. Why? Because this is the fastest way! No matter what you find in the early stages of the amplifier, you can't tell if the basic trouble is fixed unless the output tubes and speakers are working. So, start at the output. Check back through the circuit, fixing all troubles as you find them, and when you get to the input, the amplifier will be working.

When you make voltage measurements, watch the meter reading and listen also. When you touch the voltmeter prod to the plate of an amplifier tube, you will hear a small pop in the speaker if everything is working past that point. This pop won't be very loud when the plate of the power-output tube is touched, but it will be on the control grid. So, if you get the right voltage on the plate and screen, touch the grid with the prod. This should give you a louder pop, for you have gone through the circuitry of the tube, which amplifies the tiny disturbance you make when you touch the grid with the prod.

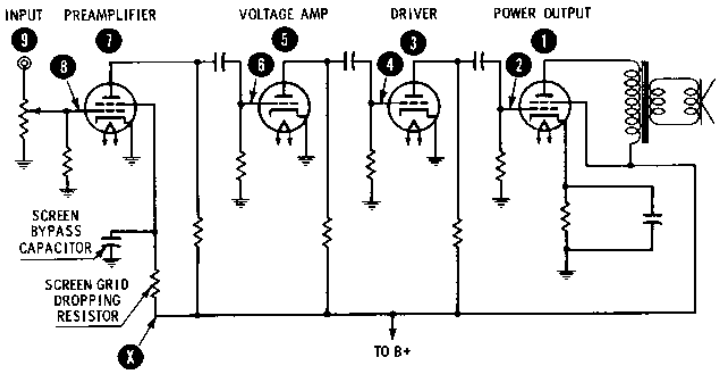


Fig. 4-1. Sequence of testing amplifiers.

Signal Tracing

As you go toward the input, you will hear louder and louder pops. This is one of the oldest methods of troubleshooting known—it was worked out back in the early days of radio where they called it the circuit disturbance test. It is still just as good as it was then, since it works every time. As you go along, watch for the stage where there is no pop. That is where the trouble is!

Fig. 4-1 shows a partial schematic of a typical amplifier. The idea is to check the signal path by listening for pops as the voltages are being checked. This path starts at the input and goes all the way through in a plain series circuit. Each time the signal passes through an amplifier stage, it gets louder (more amplification). Anything that breaks the chain will stop the signal right there. You can see the test method: Start at the output and work back toward the input. The numbers in Fig. 4-1 show the correct sequence. For this test it is assumed that the power supply has been checked and the right B+ voltage found at the filter output (X). If the output of the power supply is correct, the power supply itself must be all right, and the trouble must be somewhere in one of the amplifier circuits.

As an example, look at a typical case of trouble. Suppose you get good loud pops all the way up to and including test point No. 6. At point No. 7 you get a pretty weak pop, and hardly any at all on No. 8 (the control grid). This means that the trouble is somewhere in the preamp stage, and everything from there on is normal. The first step is replacing the tube—this is done simply because it is easiest and the problem could be a bad tube. If this doesn't help, leave the new tube in, at least until the trouble is found.

Next, measure the dc voltages around the tube—plate and screen. Assume that the plate voltage is nearly all right, but there is no screen grid voltage at all. This means that there is one of two troubles—an open screen-grid dropping resistor, or a shorted screen bypass capacitor. Either one will give the same symptom. Now you start to eliminate. (All of this work is a straight process of elimination—just keep testing until you find the bad part, once the defective stage has been isolated.)

First, measure the supply voltage at point X (the supply end of the resistor) to be sure that it is there. When you look at the schematic, it would seem that the earliest checks of the power supply output would also check out this point. Remember, however, there are wires connecting the various common points in the chassis, so these wires have to be eliminated as possible points of failure, at least indirectly. Assuming the proper voltage is present at X, the fault must be in the screen grid dropping resistor or the screen bypass capacitor. Turn the set off, and take a resistance measurement with an ohmmeter from the screen-grid tube pin to ground. If the capacitor is shorted, there will be a zero reading here—a dead short. If the capacitor is good, you will get a reading of the resistance of the screen dropping resistor plus the resistance to ground through the power supply. A normal reading here is something like one to two megohms. In this kind of circuit the screen dropping resistor is usually 820,000 ohms to 1.2 megohms.

This resistor could be open, so you take your next measurement directly across the resistor itself; the reading should be the rated value. All resistors are color coded to tell what size they are supposed to be. The ohmmeter reading must agree within 10% of this. If this resistor reads completely open, there is the trouble! Replace it with another of the same size and wattage, and turn the set on. The screen grid voltage reading will be normal. The input will now pop as loud as it should, and the input jack will give a very loud buzz or honk when touched with a fingertip—if the resistor was the only source of trouble.

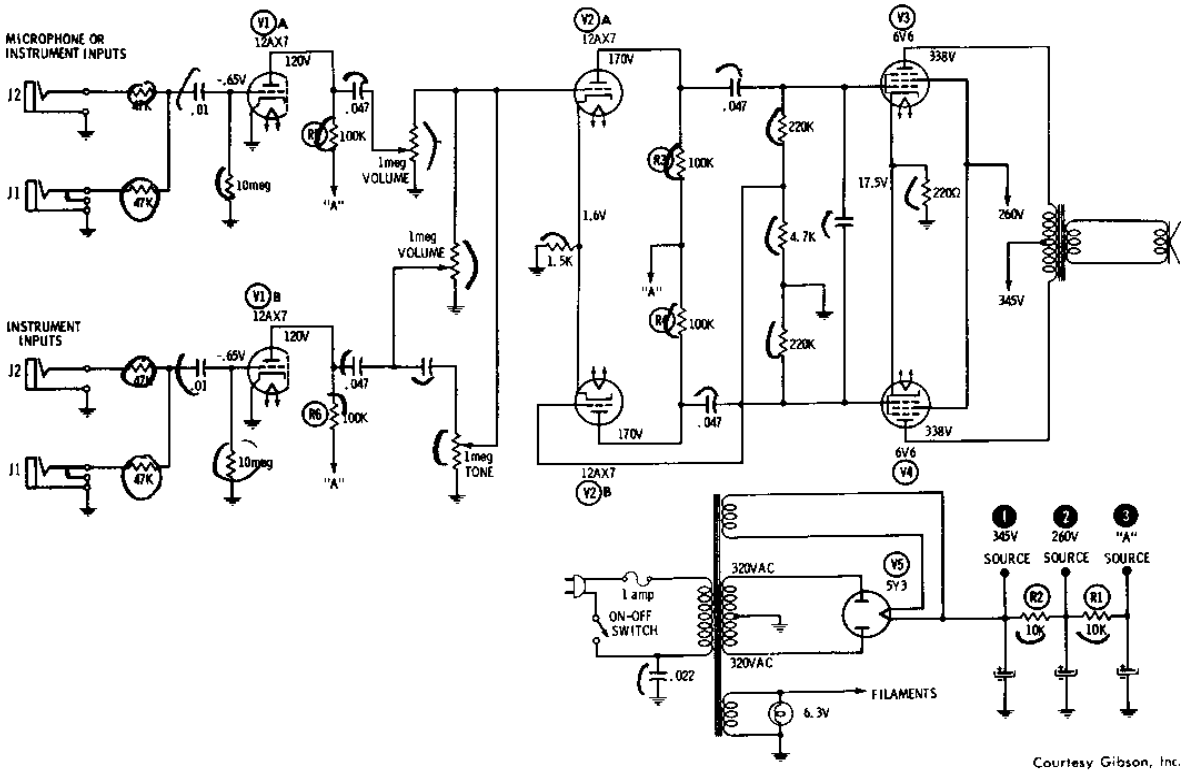
DETERMINING VOLTAGES WITHOUT SERVICE DATA

In the previous section, you made a voltage analysis of the amplifier using information gained from the schematic diagram of the amplifier. However, at times schematics are hard to find. Now see what can be done if you must test an amplifier circuit without this information. Fortunately, most of the amplifiers are conventional and since they use the same basic circuits, you can use a model amplifier for comparison. It has been done for many years. Servicing is easier if you have the service data, of course, but you can still test an amplifier and find the trouble if you know what each stage is supposed to do and how it does it. That is the reason for so much detail in the first section. How can this information be used in checking an unknown amplifier?

Fig. 4-2 shows the schematic of a commercial amplifier. This one isn't actually unknown, but it will serve as an example. What should the normal voltages be? Incidentally, there is a very valuable feature in your favor when checking voltages in vacuum-tube amplifiers—tolerance. A tube voltage can be inside a certain range, and still be all right. For example, a tube plate voltage rated at 100 volts can measure from 90 to 110 volts and still operate without affecting the performance of that stage. This is a 10% tolerance; many voltages have 20% or even slightly more. The only voltage that is really critical is the grid bias.

When you start on the unknown amplifier, the first thing, as always, is the supply voltage. Check the B+ voltage, at the filter input (point 1 on the schematic). How much should it be? A very accurate idea can be arrived at by measuring the ac voltage on the plates of the rectifier, and converting. With a normal load it can be assumed that the rectified voltage will be 10% to 20% above the rms voltage on the plates. In this one you will find about 320 volts rms on the plate, so an added 10% will give about 350 volts at the rectifier cathode for a guess.

In the circuit shown, a 10,000-ohm resistor (R2) is used as a filter choke, giving a fairly large voltage drop. The circuit indicates that the plates of the output tubes are connected directly to the rectifier output (filter input) through the primary winding of the output transformer; their plate currents will not flow through the filter resistor. This connection provides



Courtesy Gibson, Inc.

Fig. 4-2. Schematic of Gibson Model GA-6.

Table 4-1. Estimated Versus Actual Voltages

	Plate Voltage		Screen Voltage		Cathode Voltage	
Tube	**Estimate**	**Actual**	**Estimate**	**Actual**	**Estimate**	**Actual**
V1	120V	120V				
V2	160V	170V				
V3, V4	345V	345V	270V	260V		
V5					350V	345V

more voltage on the output tube plates; it also results in more hum. However, this hum is cancelled out in the push-pull output transformer, so this circuit is a practical arrangement to get a bit more plate voltage and consequently more output. Here the power-tube plate voltage will be very close to the voltage found on the rectifier cathode, or about 345 volts, since the only drop is in the output transformer.

What should the voltage be at the filter output (point 2)? The screen current for two 6V6s is being drawn through this resistor and also the plate currents of the first two tubes, 12AX7 twin-triodes. From the tube manual, screen current is about 4.0 mA for the pair of 6V6s, and 1.0 mA each should be a fair average value for the first four triodes. This gives about 8 mA current, which, by Ohm's law, is an 80-volt drop across 10,000 ohms or 270 volts at point 2.

When you examine the B+ circuits further, you will find another 10,000-ohm filter resistor (R1). This one carries only the plate currents of the preamplifier triodes (previously estimated at 4 mA for the four), so the drop across it is 40 volts. This gives an estimated 240 volts at point 3. Plate currents in voltage amplifier stages average from about 0.5 mA to 1.5 mA. The 1500-ohm cathode resistor connected to tube V2 makes the negative bias higher than on V1, and reduces the tube current. If the plate current in V2 is assumed to be 0.8 mA and 1.2 mA is assumed for V1, the drop across load resistors R3 and R4 will be 80 volts, and across R5 and R6 it will be 120 volts. Since the estimate for point 3 came out 240 volts, the plate voltage on V2 will be 160 volts, and on V1 it will be 120 volts. Thus, approximate readings for all points in the B+ circuit have been obtained.

When estimates are compared with the manufacturer's published data (Table 4-1), they turn out to be reasonably close—within 10%, in fact. Things will not always work out this well, but you see that it is possible to estimate all B+ values using some educated guesses and a tube handbook.

How do you know the size of the plate load resistors? They are color-coded so you can tell at a glance. Just find the plate connections on each socket, and look at the color coding on the resistor connected there. Any electronics handbook will tell you what the colors mean. You can also get an idea of what the normal plate voltage should be from the typical operating conditions table given for each tube in the tube manual.

Fig. 4-3 shows the complete B+ supply circuit for typical amplifier stages, beginning at the first place where dc voltage appears—the rectifier cathode or filter input. Learn this circuit; it applies to all amplifiers. If it is a bigger amplifier, there will be more; smaller ones will have less. It is always the same basic circuit. You can lift it out of the amplifier, mentally, and follow it through to see if there is any trouble in the plate voltages.

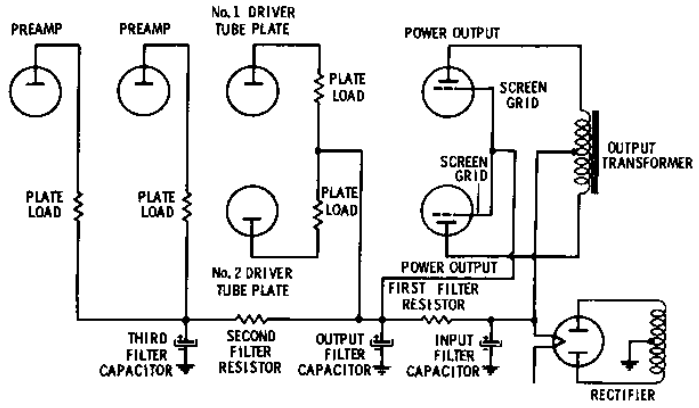


Fig. 4-3. B+ circuit of the basic amplifier.

LOCALIZING THE TROUBLE

Performance tests provide an easy way to find out just where trouble is. In other words, see just how much of the whole amplifier is working, and then concentrate on checking the part that isn't. It is easy to do. Turn the amplifier on, and make voltage and pop tests through the circuit, beginning at the output. The first time you go through a stage and it doesn't pop, there it is.

Take a typical trouble and see how to pin it down. For instance, assume the output stage and the B+ supply in Fig. 4-2 are all right, but either the amplifier does not work, or it has a very bad tone. On pop tests you find that the plate of the upper driver tube (V2A) has a pretty weak pop, and the grid of the same tube has hardly any at all. Obviously, something is wrong, but what?

Check the plate voltage; instead of the normal 170 volts or so, there is about 50 volts. This pinpoints the trouble as being somewhere in the driver stage. The first thing to check is the tube, so replace it—simply because this is the easiest thing to do, and experience has shown that tubes cause a lot of troubles. However, the results are the same, so the tube must have been all right.

To proceed, look at the B+ supply circuit in Fig. 4-2. Note that the plate voltage of this tube is fed through a 100,000-ohm plate-load resistor (R3). Turn the amplifier off, and measure the resistance of this resistor. If it has opened up or increased in value, the symptoms would be exactly what have been described. However, it checks right on the nose at 100,000-ohms, so go on to consider other possibilities. The supply voltage at the bottom or line end of the resistor is all right, because it measures the same as the screen-grid voltage on the power-output tubes checked earlier.

Summarizing the situation, the load resistor is all right, the tube is all right, but still there is not enough plate voltage. The only condition that can cause these symptoms is too much plate current being drawn through the load resistor, since it will also cause too large a voltage drop. The plate voltage is dropping across the resistor instead of across the tube. A tube draws too much plate current when the grid bias is wrong, so measure the voltage on the control grid. It ought to be zero; there is no bias voltage fed to the grid from any external source, and the 1.0-megohm grid resistor goes directly to ground.

To measure grid voltages you must use a high-impedance meter—a vtvm or high-resistance vom, since this, like all grid circuits, is a very high impedance. A low-resistance meter will cause the voltage present to be incorrect, since the meter itself acts as a shunt.

Assume that there is about 5 volts positive on the grid. This is definitely wrong. No grid in this type of amplifier ever reads positive if it is in good shape. It will be either zero or slightly negative. A 5-volt positive bias on a grid will cause the tube to draw a very heavy plate current; thus, the plate voltage will drop very badly because of the excess drop across the plate-load resistor.

Where could this voltage come from? Only a one-megohm resistor and a coupling capacitor are connected to this grid. The resistor goes straight to ground, so this is not a very likely source of voltage; however, the coupling capacitor is connected to the plate of the preceding tube, and this tube has about 120 volts positive on its plate. This is a likely suspect.

In all cases a capacitor must be a completely open-circuit to dc. The capacitor is used to transfer the ac signal voltages from the plate (output) of one stage to the grid (input) of the one following; it must always block any dc from getting through. (Although the correct name for these is coupling capacitors, you will find them called blocking capacitors in some cases.)

From the symptoms that have been assumed, it looks as if the capacitor must be leaking dc onto the grid. To make sure, disconnect the grid end of the capacitor, and hook the dc volts probe of a vtvm to the open end. Now turn the amplifier on. If the capacitor is leaking you'll read a positive voltage on the open end. This should be zero, of course, since a good capacitor is a completely open circuit for dc. A normal capacitor with good insulation will give just a very slight kick of the meter needle as it charges up. Then this reading will slowly leak off through the input resistance of the meter. If you have any residual reading, any voltage showing at all after the first charge has leaked off, the capacitor is bad and must be replaced.

Fig. 4-4 shows how this test is made. With the capacitor hooked to the grid resistor as in the original circuit (Fig. 4-2), you will probably read 5 to 6 volts dc. With the capacitor disconnected, you may read as high as 35 to 40 volts positive dc on it if it is leaky. The input resistance of the vtvm (11 megohms average) is much higher than the 1-megohm grid resistor. If you use a vtvm for this test, set it on a low dc volts scale. If you use a vom, set it on a voltage scale that will carry the maximum voltage to be read. In this case it is the 120 volts on the preceding tube plate. You can't blow up a vtvm with a voltage overload, but you can damage a vom, so be careful. After the first charging kick, set the meter to a lower voltage scale. For the final test use the lowest scale available;

even one volt positive through a coupling capacitor means it must be replaced.

You cannot make a leakage test with a common ohmmeter. The actual leakage through these capacitors is very small. If you could measure it, the resistance would go up to almost 100 megohms (far above the capacity of a service ohmmeter), but the capacitor will still leak enough to cause a lot of trouble. The voltage test is sure and fast, so use it.

Capacitor leakage is a very common trouble; that is why it is used as an example. It will cause loss of volume, a very bad distortion, and even damaged tubes if the leakage is bad enough. All of these problems result from the change in the grid-bias voltage. The amplifier tubes are driven into a very nonlinear part of their operating range, and the tone suffers very severely as a result. In fact, after a little practice you will almost be able to identify the problem by listening to the amplifier. Leaking coupling capacitors give the tone a characteristic muffled sort of sound that is easy to spot.

Now examine the process that you went through and the methods you used to find the trouble. Can you see the orderly steps in the example just given? The amplifier was examined one stage at a time, until a stage that was not doing its job was located. You stopped right there, found that trouble, and fixed it, before going any farther.

You used a process of elimination to find the defective component. In electronics work there are always several things that can cause any given trouble. Did you notice that things were eliminated one at a time, until the faulty item was reached? First the tube (it is the easiest), then the plate supply voltage, next the plate load resistor, and finally the real villain, the leaky coupling capacitor were checked out. There are only a certain number of parts in any circuit that can cause any given trouble. Patiently eliminate them one at a time, and eventually you will find the right one.

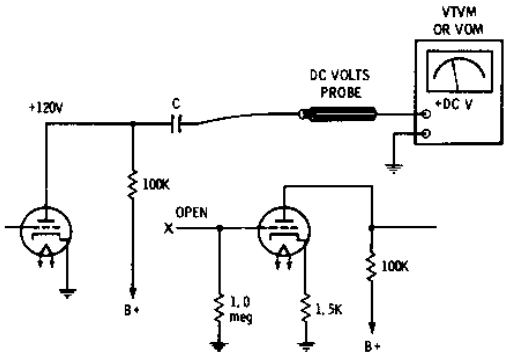


Fig. 4-4. Testing a coupling capacitor for leakage.

You may find it the first time; on the other hand, you may have to go all the way, as you did in the example. Just keep on until you find it. Later in this book there are more elaborate tests using complicated equipment. However, you will find that in this, as in all other electronics work, the majority of the troubles can be located and fixed with only very simple test equipment plus a good bit of plain old common sense. This is because a very large percentage of troubles are simple ones—a dead tube, a burned resistor, a leaky capacitor, and so on. Even the more complicated troubles will have very simple causes.

Always remember the process of elimination, and use it. If you know how each circuit works, you can quickly find the one that is not working, and start from there. There are some other tests later in this book that will help in the more difficult cases.

TRANSISTORS VERSUS TUBES

Only about 5 years ago the transistor was being hailed loudly as the answer to all the problems in electronics. Needless to say, this prediction hasn't come true. Transistors have advantages, but they're not the answer to all of our problems.

The transistor is a useful device and is ideally suited for certain applications. They do work, but there are, as usual, certain difficulties. These have led quite a few of the major amplifier manufacturers to go back to tube-type amplifiers, especially in the very high power ends of their lines. You'll see several examples of this in the Commercial-Amplifier section in the back of this book.

Among the main difficulties was the frequency of catastrophic failures or "avalanches." (One transistor blows, and it's followed in about 50 milliseconds by about five others!) Transistors with very high power ratings were difficult to obtain, without the need for stacking or paralleling, always one of the worst jobs in engineering. Finally, production transistors have a very wide "parameter-spread"; tubes, on the other hand, match one another very closely. (However, as this edition is being written, very high-power transistors, with high breakdown voltages are being perfected. These will undoubtedly show up in amplifiers very shortly.)

The wide parameter spread makes precisely matched pairs hard to find, and expensive. Contrary to some ideas, transistors aren't cheap, especially in the high-power types. A very high-power transistor can cost up to two or three times as much as a vacuum tube with approximately the same power rating.

The "immortal transistor" is another fallacy. At first, we were told seriously that the transistor would

"last forever" in actual service. It has no filament to create heat, no cathode to become exhausted, it was perfectly sealed against environmental contamination, and so on. So, it could be soldered into the circuit as a permanent part. That statement must be amended to fit the truth as it is today.

Transistors do not "get weak" and lose amplification, as tubes do. But, they can develop quite a few other defects that cause a loss of gain, such as leakage, etc. So, they must be tested just like any other part. In fact, from my experiments and experience in actual bench-servicing of guitar amplifiers, the first think I look for, now, is a bad transistor—exactly the same technique we used in the servicing of tube amplifiers.

Before we go any further, let me say this: the modern, *well-built*, correctly designed transistor amplifier is a *very* good piece of equipment. If the transistors operate within their safety factors, run cool, and the unit is properly serviced, a transistor amplifier will give just as good service as any other. If you understand the operation of transistors, you'll have no real problems in servicing transistorized amplifiers, and keeping them up to par.

Incidentally, there has been a great deal of material published on transistors. Much of this, quite frankly, is useless to the service technician. You do not need to know all about how a transistor is *built*. All you have to know is how it works! It is the *function* of the device, and not its detailed structure, that matters. So, if you know how a transistor amplifier stage works, and what dc voltages to expect on any element, and that sort of thing, you will be able to service this type of equipment just as quickly and easily as you do tube amplifiers.

One of the bigger headaches is finding suitable replacement transistors, In too many cases, we cannot get exact duplicates, of the same type number, without too much delay. However, the replacement transistor manufacturers—Motorola, RCA, Sylvania, etc.—do have general replacement types which will work in practically all circuits. There is a method of selecting replacement transistors—we'll take this up in detail in just a little while. Used properly, this will let you choose a suitable replacement for any kind of transistor. This has been verified by several years of actual experience in commercial amplifier servicing.

THE NUMBERS GAME

Unlike tubes, the numbers on an original equipment transistor are often entirely meaningless. Every amplifier you open up for service will probably have different transistor numbers. This is almost universally true in import amplifiers, and often in U.S. built units. A few of the better companies do use standard-numbered replacement types, but I am afraid that you'll find a great many with what are called "in-house numbers."

In other words, the manufacturer buys a batch of transistors to meet his specifications. Then, he assigns his own type numbers to these, meaningless to anyone but his own stock clerks.

At regular (and quite frequent) intervals, the replacement transistor manufacturers publish listings of all the transistor numbers they can find. In quite a few cases, you'll even be able to find a listing of the number on the original part, and a recommended substitute. These lists are long—one manufacturer lists something over 38,000 different types of transistors! However, something like 35 to 40 replacement transistor types can be used to replace any of these. These replacements will work. In practically all cases, the transistor makers have run tests to make sure that they will.

Being skeptical by nature, I ran my own test series not too long ago, to find out if this was really true. It was! In no case did I find a replacement transistor listed that would not give service equal to or better than the original. However, if you should run into any difficulties, you can use the method to be given, to cross-check the specs of the original against the recommended replacement.

SERVICING TRANSISTOR AMPLIFIERS

What's the difference between transistor amplifiers and tube amplifiers? What different service methods must you use to work on solid-state equipment? The answer to both of these questions is the same—none. You use exactly the same methods, test equipment, and service procedures that you'd use on a tube type to check out a transistor amplifier. Why? Because all amplifiers do exactly the same thing—amplify a signal. So, if you use the *signal* as your reference, you can check out any amplifier and find the trouble in the shortest possible time. All of these amplifiers have a normal input signal of about 50 millivolts, and they amplify this to about 50 watts (100, 200, makes no difference!)

So, you'll see that while there is apparently a big difference in the appearance of the two types, there is absolutely no difference in their *action*. You'll still be able to use dc voltage readings, resistance readings, and, fastest of all, signal-tracing tests. The basic method is very simple. Feed in a known input signal, follow it through the amplifier with a scope, until you find out where it stops. Then, take dc voltage read-

ings, and make resistance tests, and you'll find the defective part.

Things will look different, of course. Instead of working with +200-300 volts, you'll be reading lower dc voltages, say from about 16 volts of either polarity up to maybe 60-75 volts. Sometimes, dc voltages of both polarities will be found in the output stages. Instead of plate currents around 100-150 milliamperes, you'll have collector currents of up to 3-5 amperes, and so on. These are "differences of degree" only. The schematic diagram will tell you what the normal voltage readings should be. The basic test procedures will still be the same. Now, let's look at some transistor circuits in detail, and see how they're made. Just as in tube amplifiers, the circuitry has become pretty well standardized. If you know the few basic circuits, you're in good shape. You'll find them used in all amplifiers.

THE "HOT TRANSISTOR"

The transistor has several advantages over tube-type amplifiers. For one, less heat is generated inside the cabinet. Contrary to what you might think, transistors do *not* run cold. If you think so, carefully touch one of the big power transistors in an amplifier after it has been running for a while. Heat dissipation is a major problem in power transistors of all sizes. While they do not run as hot as tubes, heat is generated due to the normal power loss in the transistor, and this must be carried away to keep it cool, or as cool as possible.

A good deal of heat is generated in the collector-emitter junction of a power transistor. The early germanium transistors had a bad habit of getting hot, then developing some leakage, which in turn made the junction run even hotter, which caused more leakage, and so on and on until the transistor went into what was called *thermal runaway* and destroyed itself. The silicon power transistors now used almost universally aren't quite so bad about this; in fact, they will not go into thermal runaway, if kept anywhere within reasonable limits. They can withstand temperatures almost double those of the older germanium types.

The collector is internally connected to the case of the transistor, electrically and "thermally." This helps to get the heat away from the junction and outside of the transistor, where it can be radiated away. The cases of larger power transistors are mounted on big flat sheets of metal, called *heat sinks*. Due to their larger area, they radiate the heat away into the air.

This brings up another problem. The heat sink must make a good thermal contact to the transistor case. Yet, it must be electrically insulated from the chassis so that the collector voltage won't be shorted. This is accomplished by using very thin mica insulators between the case and heat sink. These insulators are coated on both sides with a special *silicone* grease. This grease helps the heat transfer between case and heat sink, but gives good electrical insulation. When replacing power transistors, you must be sure that the case is perfectly insulated from the heat sink, and that the mica insulator isn't cracked or damaged. Be sure to coat both sides of the insulator with the silicone grease. Leaving this "dry" will reduce the heat transfer by a surprisingly large amount.

SMALL-SIGNAL AMPLIFIER STAGES—CIRCUITS

Practically all of the "small-signal" stages in transistor guitar amplifiers will use a common-emitter circuit. This is exactly the same as the grounded-cathode circuit found in tube amplifiers. The base is the input, the collector is the output, and the emitter is common to both, thus the name. These are the stages known as voltage amplifiers in tube circuits. In the transistor amplifiers, they're usually called small-signal stages. Voltages will be much lower and currents will be slighter larger than in tube types. However, there will be enough *voltage* amplification to let us use our fastest test methods. These stages do the same thing—build up the very small input signal to a voltage (and power) level high enough to drive the power-output stages to full rated output.

So, we can use exactly the same tests as before. Fig. 4-5 shows a basic circuit of a typical transistor amplifier. (A lot of components have been left out, but this is the complete *signal path.*) You can make your tests in the same way as before—either "back to front" as shown in Fig. 4-1, or you can use the signal-tracing method shown here.

SIGNAL-TRACING TESTS

Let's assume that the amplifier is dead. It won't pass a signal from the input to the output. Dc voltage supply is assumed normal. So, we have our first fact; the signal path is broken somewhere between the input and output. To locate this break, in the least possible time, is the object of all troubleshooting methods. With signal tracing, it can be faster.

Refer to Fig. 4-5. Feed in a known input signal, say 400 Hz at about 50 millivolts. With a scope, check this level at Point 1, then at Point 2, and so on, going from base to collector of each stage. Normally, you'll see a good deal of voltage gain from input to output of

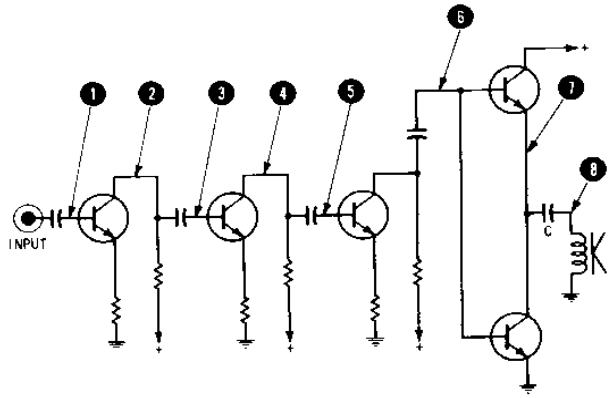


Fig. 4-5. Basic circuit of transistor amplifier showing the signal path.

each stage. In certain stages, you may only "break even." This is a typical characteristic of current-amplifier stages; the signal *voltage* will be almost the same at input and output. However, this is all right. What you're looking for is a stage which has input, but no output at all.

Since this amplifier will not pass a signal from input to output, there's a stage like this in there somewhere. When you find it, stop. You've found the trouble. Now, lay down the scope probe, and use the vtvm. (Here, and from now on, vtvm means any very high-impedance voltmeter, whether tube or transistor type.) Read the dc voltages around the dead stage. These will point out the type and location of the fault. Each one will have its own peculiar reactions on the dc voltages, as you'll see very soon.

TRANSISTOR PECULIARITIES

Transistors differ from tubes in one important way. A vacuum tube, with plate voltage applied, but no bias (same voltage on grid and cathode, or "zero bias") conducts a pretty heavy current. A high negative voltage must be applied to the grid to make the tube stop conducting. A transistor is different. With zero bias (same voltage on both base and emitter) it will not conduct current at all. This is one thing you must remember, for it is a very important clue to trouble.

This applies to all transistors, of any size, polarity, or type. A small bias voltage must be applied to the base, in a *forward* polarity. This is usually 0.2 volt for germanium transistors, and 0.6 volt for silicons. If this minimum bias isn't there, the transistor will be cut off.

You will seldom find transistors in audio amplifiers, such as guitar amplifiers, with only "cutoff bias" applied. In applications such as transistor TV, yes, in certain circuits. However, all small-signal stages in guitar amplifiers must work in Class-A, and this means a bias slightly greater than cutoff, for distortion-free operation of the stage. (In the output stages, working in Class-B, you'll find power transistors biased *almost* to cutoff, but not completely, for reasons which will be explained later.)

A transistor which is cut off is not conducting. So, there is no current through the load resistor, and there is no signal to pass along to the next stage. Also, there is no current through its emitter resistor. Remember these two facts; they're very important clues in testing for faults. Like the plate-cathode current path in tubes, the collector-emitter path in transistors is the important one. The lack of current flow here will cause two symptoms; the collector will read the full dc supply voltage, and there will be no voltage on the emitter at all.

This condition can be due to one of two things: incorrect bias (zero) due to trouble in the bias network, or to an internal open-circuit in the emitter-collector circuit (base-emitter or collector-base since the base is a part of both circuits.)

Transistors can short internally, also. In the basic circuit of Fig. 4-5, an emitter-collector short will probably burn up the emitter resistor, due to the high fault-currents. In circuits with higher resistance, you'll read the same voltage on the base as you have on the collector or the same voltage on emitter and collector. To make sure, take the transistor out of the circuit and make ohmmeter tests or use a transistor tester.

IN-CIRCUIT OHMMETER TESTS OF TRANSISTORS

The ohmmeter is very useful for transistor testing, in-circuit and out. In troubles like those just described, turn off all power and take resistance readings between all elements of the transistor. You can quickly locate either an open junction or an internal short.

There's a special test you can make with the ohmmeter. First, find out which lead of the meter has the positive battery voltage connected to it. (In voms, it is often the black lead; in the average vtvm or FET vom, it will be the red lead.) You can use this to find out the polarity (type) of an unknown transistor, and tell whether it has either a shorted junction or an open one.

For npn transistors like the ones shown here, put the positive ohmmeter lead on the base. You should now read a low resistance to both collector and emitter. Reverse the ohmmeter prods, and you should read a much higher resistance to both elements. If you get an open circuit reading between any pair of elements, either way, they are open. If you get a short-circuit reading both ways between any pair of elements, they're shorted. This is exactly the same kind of results you'd get if you were checking a diode, out of circuit. So, this is called the "diode-effect" test when used for checking transistors.

If you get a short reading across two elements of the transistor, take it out of the circuit, and repeat the tests. If you get the same results, all right; the thing is shorted. However, if the transistor reads good, out of the circuit, go back and check the circuit. Some of the parts are shorted, but the transistor itself is good. Check the resistances around the open socket of the transistor. For checking resistance values which may be suspected, you'll have to remove the transistor; otherwise you'll have the diode-effect in the circuit and get wrong readings, which makes things very confusing!

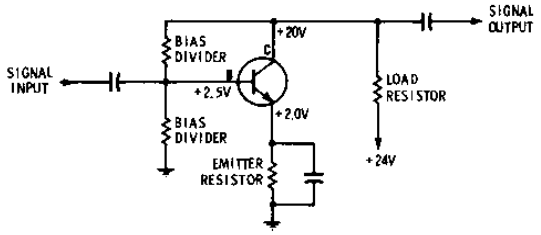
CIRCUIT VARIATIONS

There's an old French saying, "The more things change, the more they stay the same." This was never more true than in transistor circuits. You'll find examples of this in many amplifiers; circuits that look upside down, backward, and so on. However, if you look at them from the right viewpoint, you'll see that they *are* still the same. One good example of this is our old friend the common-emitter circuit.

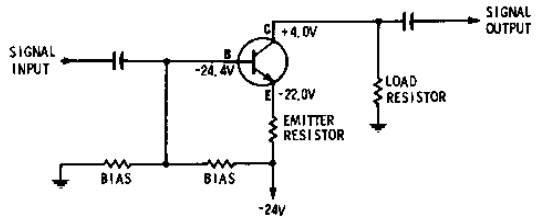
Here are its characteristics. The collector is always reverse-biased, with respect to the emitter; for an npn transistor, this means that the collector is highly positive to the emitter. The base must have a slight forward bias for the transistor to conduct; again, with respect to the emitter. Remember these. Now let's see how they can be used.

Fig. 4-6A shows one of these circuits, with the voltages applied in the "conventional" way, like those in a tube stage—input signal to the base, output signal taken off the collector, dc voltage fed to the collector through the load resistor. Dc voltages on the transistor are measured from the emitter.

Now, look at the circuit of Fig. 4-6B. Does it look entirely different? It is not. Here, the collector is grounded through the load resistor and a negative voltage is applied to emitter and base. However, if you'll take the voltage readings *from the emitter*, you'll see that all voltages are exactly the same as before! The collector is 18 volts *more positive* than the emitter. The base is still +0.6 volt more positive than the emitter. So, everything is right back where it was! The only difference between the two is the point where the *ground* is connected.



(A) Voltage applied to collector.



(B) Voltage applied to emitter and base.

Fig. 4-6. Common-emitter circuit.

In Fig. 4-6B, the collector current still flows through the load resistor in the same direction, and, if you'll notice, develops exactly the same voltage drop across this resistor, meaning that the signal amplification is the same (4.0 volts drop in both cases). The signal once again is taken off through the coupling capacitor and fed to the next stage.

Note the voltage-divider resistor network used to provide the proper base bias in both circuits. This is a very good circuit, and a common one. These resistors have a ratio which applies the proper bias voltage to the base. There is a variation of this, in which the "ground-end" resistor is left out. Its place is taken by the internal resistance of the base-emitter junction of the transistor. This saves one part, but does not work quite as well as the full divider circuit. The results are about the same. For a definite reference, look up the dc voltages given on the amplifier schematic. This will show you what to expect in any stage.

The collector voltage in either of these circuits will provide you with a valuable clue as to the operation of the stage. Note that in the circuit of Fig. 4-6A there is a 4.0 volt drop (+24 volts −20 volts on collector); this shows that there *is* current flowing in the collector circuit. In the circuit of Fig. 4-6B, there is no applied voltage, but the collector current still develops its 4.0-volt drop across the load resistor. If the collector voltage in the Fig. 4-6A circuit reads +24 volts, the same as the supply voltage, then you know that this transistor is not conducting, and thus not working. Find out why. In the Fig. 4-6B circuit, if the collector voltage is zero, same thing—no current, no conduction, and no signal output. Check the base-emitter bias, or check for an open transistor.

The Emitter Voltage

There's one handy quick-check, for all common-emitter stages. This is the emitter voltage. If there is a resistor from emitter to ground, or to the voltage supply as in Fig. 4-6B, check for the voltage *drop* across this resistor. If this is normal, this stage is conducting current, and is probably all right. With no emitter voltage there is no current or amplification; the transistor is open, the emitter or collector resistor is open, or the transistor is biased-off.

SIGNAL TRACING CAPACITY-COUPLED CIRCUITS

If your amplifier is dead, but the dc voltages are all proper, this symptom points to one of two things—an open coupling capacitor, or broken wiring in a "signal-only" circuit. Something has stopped the signal, but left the amplifier stages working, as far as dc voltages are concerned.

This is easy to find with signal-tracing methods. Feed a signal into the input, then quickly check it through the amplifier signal path with the scope. Look for the point where you find signals on the input side of a coupling capacitor, but none on the output side. There you are! (In one actual test, an open capacitor was located with this method in exactly 73 seconds.) When replacing the electrolytic capacitors commonly used for couplers in these circuits, observe the polarity.

SOLID-STATE AMPS—FINDING VOLTAGES WITHOUT SERVICE DATA

Earlier, you saw the method of determining what dc voltages should be found in a tube amplifier, without any service data. This will work just as well in transistor amplifiers. Go to the dc power supply, and read the maximum output voltage. This will be the voltage used on the output stage; you should find this voltage on the "hot collector" or power-input point of the output pair.

The small-signal stages will often use lower voltages. Starting at the highest dc voltage point in the power supply, follow the dropping resistors. These will normally be higher wattage than the types used in tube amplifiers. They must handle somewhat greater currents than the tube resistors, so they'll be bigger and easier to locate. Key point—look for a large resistor going from the high dc point to a big electrolytic capacitor. Decoupling and filtering in transistor amplifiers must be very good indeed, to prevent regeneration and oscillation.

You may find two- and three-section dropping resistor networks in these amplifiers. The farther we go through the dc supply network, the better the filtering. The input transistors must have an absolutely "pure dc" supply, to reduce the hum to the lowest possible level. Transistors are more sensitive to hum than tubes. More filtering will be used to eliminate this.

SELECTING REPLACEMENT TRANSISTORS

As we said earlier, getting a suitable replacement transistor, for an unknown type, can be a problem. In most cases, you'll have two alternatives. One, get an exact duplicate of the original from the manufacturer of the amplifier. Two, select a suitable replacement from one of the Replacement Guides. If your shop is a "Factory Service Agency," you'll have the exact duplicates in stock. However, if this is a strange instrument, or one of the unknown-make import types, you've got a problem. In a lot of instances, you will be able to find the stock number or type number of the bad transistors listed in the Replacement Guides. The replacements listed in these guides will work; at least, they have in all of the tests we made.

If neither of these alternatives can be used, and you have a completely unknown type to replace, there's still a way to do it. Fortunately for us, transistors are *not* nearly as critical as they were once supposed to be. They have a pretty wide "parameter spread;" in other words, the operating conditions can vary over a pretty wide range, with no loss of performance. Replacement tubes are made with almost precisely the same characteristics in every manufacturer's line. Transistors, even of the same type number, can have characteristics which vary quite a lot. The amplifiers are designed to handle this variation, which makes our job a lot easier.

First of all we can say this: all bipolar transistors are *alike*. They're all triodes, with a base, an emitter,

nd a collector. There are two major differences—the ype, pnp or npn, and the material, germanium or ilicon. So, this is what we must find out. Get a piece f scratch paper, and make up a list. What we're oing to do is find the characteristics of the *original* ransistor, so that we can find a duplicate.

First, we need the type, npn or pnp. If you have a chematic, this is easy. Look at the emitter arrow. If it points toward the base, it's a pnp; if it points away from the base, it's an npn.

To determine the material, germanium or silicon, check the voltage between base and emitter. Silicon transistors need a 0.6 volt base-to-emitter voltage to reach the conduction threshold. Germanium types need only 0.2 volt. In most of these circuits working in Class-A, the bias will be slightly above this value. However, if the bias voltage is *less* than 0.6 volt, the transistor *has to be* a germanium. If it's 0.6 volt or slightly more, it is most likely to be a silicon. (In practically all of the later model amplifiers, *all* transistors will be silicons, from the small-signal types to the power outputs. Silicon transistors have quite a bit better leakage characteristics, and they will be found in the great majority of amplifier circuits today.)

Now, we have two things. Next, what kind of stage is the transistor working in? There are three groups—small-signal, including preamplifiers and all small transistors up to the drivers; the drivers, which must have a slightly higher power rating, and the power output types. With a schematic diagram, you can look at the position of the transistor in the circuit and tell how it is being used.

In the small-signal types, we don't have to bother about anything except voltages. These transistors work with very small currents, well within the ratings of even the smallest types. So, without the schematic to tell us, we can read this voltage from the transistor terminals and find out. Take the defective transistor out of the circuit. If possible, identify the basing; emitter, collector, and base. (Compare the type against the base diagrams in the Replacement Guides.)

Turn the amplifier on, and read the dc voltages on the three holes in the PC board. The chances are that this transistor is working in a common-emitter circuit, with an emitter resistor, as in Fig. 4-7. Now, what voltages would you read with this transistor out of the circuit? You would read the full dc supply voltage on the collector terminal, the normal base-bias voltage on the base terminal due to the voltage-divider connected from the dc supply to ground, and zero voltage on the emitter terminal. There is no current flowing in this circuit, so there is no voltage drop across the emitter resistor. You can often identify parts in this circuit visually. Look for a small resistor from one terminal to ground; the chances are that this will be the emitter resistor. If there is a bypass capacitor across it, even more so.

This gives us what we want to know. The dc voltage on the collector will be the maximum voltage applied to this transistor in actual operation, since we will have a good bit lower voltage with the transistor working (drawing current) than we do now, with only the meter drain to load it. The *polarity* of this voltage gives us the type of transistor—pnp or npn. If it is an npn, as in Fig. 4-7, the dc collector voltage will be positive. (Collectors are always reverse-biased, remember?) If it is a pnp, the collector will be negative.

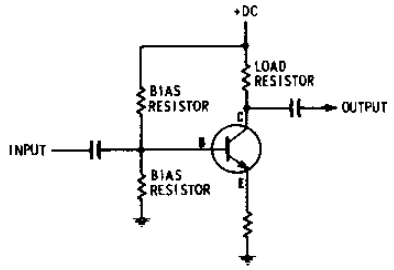


Fig. 4-7. Typical transistor common-emitter stage.

Now we've got a few facts, so we can start making out our list of the characteristics of the original transistor. For example, we need a preamplifier transistor, npn, very probably silicon, that has a maximum of 20 volts on its collector.

We're ready; now, we get one of the Replacement Guides, and start looking through the characteristics charts in the front (or back) of the book. The Motorola HEP Guide shows quite a few types that should work. For instance, a HEP-53 npn, silicon, breakdown voltage 30 volts. This is above our maximum voltage, but for peace of mind, let's keep on. We find a HEP-738, same characteristics, but a breakdown voltage of 40 volts. That's better. HEP-53 is in the TO-5 case, round metal 0.35 in. wide. HEP-738 is in the TO-92 case, a very small epoxy type. So, if the location is crowded, we can always get this one in.

There are many others. RCA's SK-Guide shows an SK-3024, same characteristics, TO-5 case, and a breakdown voltage of 90 volts. Sylvania lists a type ECG-128, same characteristics and a breakdown voltage of 80 volts. General Electric's Guide shows a GE-10, TO-92 case, 25-volt breakdown. So, you can see that any of these transistors would work in this circuit; the major consideration here is to get one with ample safety factor to avoid breakdown from high voltage.

So, there it is. That's the basic method. You make up your scratch-paper list of the characteristics of the

original transistor, then match them as closely as possible. Be sure to choose a replacement with a collector-emitter breakdown voltage well above the maximum voltage applied to the original transistor. The actual basing of the replacement is not at all important. You can always twist the leads around to go into the correct holes in the PC board. Spaghetti can be slipped over one or more leads if they are too close together. The basing of the new transistor will be shown on its package.

After replacement, turn the amplifier on, and check for the dc voltages on each element. Better still, feed a test signal into the amplifier, and read the waveform on input and output of the new transistor. This is the fastest and surest way of telling whether the replacement is going to do the job. If you do run into trouble, such as clipping, for example, try a transistor with a slightly *lower* beta than the first choice. This seldom happens, but it could.

There is one other "method" that can save a lot of work. Check over the amplifier and see if there is another transistor in there with exactly the same numbers that you found on the defective one. If so, take it out (making a careful sketch or note of how it is connected) and test it. Your transistor tester will tell you, very quickly, its type, and its beta reading. It will often tell you whether it is a germanium or silicon, although there *is* a small chance of confusion, in one way. A small-signal transistor with absolutely no leakage at all will probably be a silicon. If it shows a small amount of leakage, it could be a germanium. (Small leakage is normal in germanium transistors.) With this data, plus the measured dc voltages, you can make up your spec sheet much faster. The use of identical transistors in several preamp and small signal stages, fortunately, is pretty common.

SELECTING DRIVER TRANSISTORS

To find a replacement for a driver transistor, use the same method. However, since driver stages need a little more power output, you'll have to check the current and power ratings of the replacement. In smaller amplifiers, you'll find that drivers will be rated at about 5 watts, as a sort of ball-park figure. These drivers will be in TO-5 cases, and have dc voltages up to say 25 volts, with currents that are in the 25-50 mA range.

In the bigger amplifiers, you may find dual driver stages; a medium power type, driving a driver transistor that may be of the same type as the big output transistors. This would be most likely in the 100-150 watt class of amplifiers, where a lot of drive power is needed to push the output pair to full output.

For medium-power driver transistors, the lists will show you such types as RCA SK-3048, 5 watts, 30 volts breakdown; SK-3024, 5 watts, 90 volts breakdown; both npn's. For pnp, SK-3025, 7 watts, 90 volts breakdown. In Motorola, HEP-242, 6 watts, 40 volts breakdown, pnp. Duplicate in npn, HEP-243. Sylvania, ECG-152 and ECG-153 are similar; 40 watts max, 60 volts breakdown. So, as you can see from these examples, there are many driver transistors that will work.

POWER TRANSISTORS

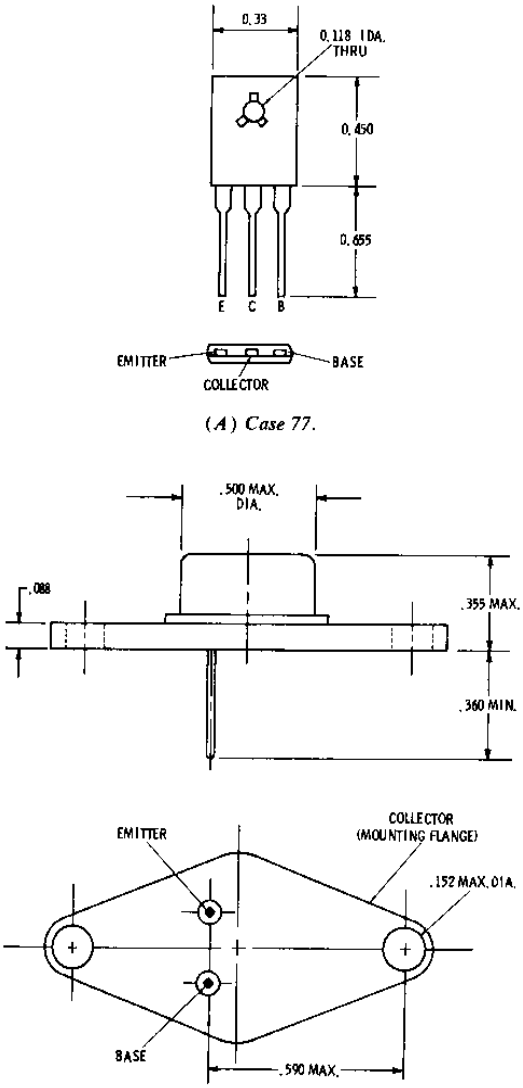
Now, we come to the "big boys"—the power-output transistors. You'll find some of these with amazingly high power-handling ability. Some can actually dissipate 100 or even 150 watts. Bass amplifiers (which need the greatest power), vocal amplifiers, and other instrument amplifiers are now being built in all solid-state designs with total undistorted power outputs up to 300 watts. In most cases, as you'll see by the schematics in the back of this book, the amplifier will be designed with two output "channels," each one feeding a single speaker or speaker system, 150 watts each, for a total of 300 watts UPO (undistorted power output). The actual peak power will be something like double that, but is not usable due to the increase of distortion.

At the time this is being written, 150 watts UPO seems to be about the practical limit. By the time you read this, there may be higher-powered devices available. However, they'll all use the same circuitry, only the voltages and currents will be different.

Some of these stages use a comparatively low voltage, but the current, of course, is higher. For example, 30 volts on the collector, with a current of 5.0 amperes, equals 150 watts of power dissipation; 80 volts collector, at 2.0 amperes, about the same. Note that this refers strictly to the power-dissipation ability of a *single* transistor, and not to the total power output as developed across the speaker. This will be discussed very soon. What we need now is the absolute maximum that will show up across this transistor, so that we can find a replacement type that will stay in there and take it. This means choosing one with maximum ratings much *higher* than the normal maximum voltage/current product applied to the transistor in actual service, so it will not be overloaded, or run too close to its maximum rating. Overloaded transistors run very hot, and don't last too long.

Cases and Mountings

In low-power and medium-power applications, say from 5 watts up to 35-50 watts, you'll find power



(A) Case 77.

(B) TO-66 case.

Fig. 4-8. Cases for low- and medium-power transistors.

transistors in the flat three-lead cases called case 77. Fig. 4-8A shows these. Typical examples of this type are the Motorola HEP-245 and HEP-246. Some transistors in this power range will be in the TO-66 case, shown in Fig. 4-8B, which is the familiar "diamond-shaped" case with the dome, like the larger TO-3.

Fig. 4-9 shows the TO-3 case used in almost all of the very high-powered types. In these (and in the preceding types as well) the collector of the transistor is electrically and physically connected to the case. This is done to get heat away from this junction as fast as possible. The flanges of the case are bolted tightly to large heat sinks.

Use the same method of selecting replacements that you did before. Now, you *must* match the case-type, but this is easy; they'll mostly all be in TO-3 cases anyhow. You'll find the high-powered types listed in all of the Replacement Guides, except in rare cases. When this happens, use the "breakdown voltage/maximum current/maximum power dissipation" checklist.

For example, in one of the very high-powered amplifiers, Ampeg's ST-42, with 120 watts UPO a total of four RCA type 10003 power transistors are used, two in each half of the OTL pair. Checking the Replacement Guides, you'll find that RCA lists an SK-3036, Motorola a HEP 707, Sylvania an ECG-130, and so on. (The number of "10003" is an "industrial device" number; others with similar characteristics will be found in the "40000" series, and so on. Same thing; they're all just big power transistors!)

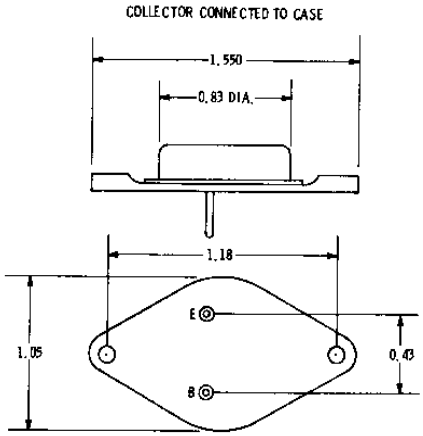


Fig. 4-9. The TO-3 case used for high-power transistors.

Heat Sinks and Mountings

When you replace any high-power transistor of a type big enough to need a heat sink, be very sure that you get *all* of the insulators, etc., back *exactly* as they were. Don't forget to check that little mica insulator. If it's cracked or broken, use a new one. You'll find a new one packed with each replacement power transistor. Even if the silicone grease wasn't originally used between the transistor case and insulator, and insulator and heat sink, put it on. This helps the heat transfer between transistor case and heat sink, and helps the insulation, too. Replacing a transistor "dry" can let it run several degrees hotter than it should.

Matching Output Transistors

You'll find that all of the big power transistors are used in pairs. Single power transistors are found only in the small amplifiers. The most common failure in

these Class-B circuits is a breakdown of one or the other of the power transistors in the output pair. For some unknown reason, both transistors seldom blow at the same time. The "top transistor," that is, the one which is directly connected to the power supply, seems to be the one which fails the most often.

Regardless of which one is bad, always replace *both* transistors. This is necessary to get a good match between the two devices. Replacing only one and leaving one of the originals still in there, can result in a bad mismatch of characteristics. The least important result of this would be a bad distortion; the worst would be early failure, perhaps of the new transistor.

You can get specially selected "matched pairs" of power transistors in all replacement lines, either for the stacked circuits, with both transistors of the same type, or the complementary-symmetry circuit, with transistors of identical characteristics but opposite types. For example, Sylvania's ECG-130-MP, which is a matched pair of replacements for the big 10003 transistors; RCA shows a "SK-3037," which is a matched pair of SK-3036s, and so on.

For complementary-symmetry pairs, one pnp and one npn, you'll find listings of special complementary pairs. RCA's SK-3024/3025, Motorola's HEP-245/246 in the 30 watt range, or HEP-247/248 in the 100-150 watt range, and so on. Or, if you can't find exactly what you need in a factory-matched pair, look up suitable types in the listings. You can get a very good match by checking the proposed replacements on your transistor tester, and comparing the beta readings, etc. There is only one pitfall you must watch for: DON'T pick a silicon type for one and a germanium for the other. The distortion that this causes has to be seen to be believed! (For obvious reasons, I will not disclose exactly HOW I got this little gem of information but you can believe it. This is borne out by actual experience.)

Replacing transistors is not at all hard, if you go at it in a logical way. Just make up your list of characteristics, and then allow yourself as high a safety factor as possible. If you do this, your replacements will work just as well as the originals: in some of the import amplifiers and the cheaper types, even better!

TROUBLESHOOTING THE TREMOLO CIRCUITS

The first symptom of trouble in the tremolo circuit will be the absence of any tremolo effect in the tone. With the strength control wide open the tone will still be plain. This can be checked out just as you would any other trouble. The first thing to check is the tremolo oscillator tube. Replace it and see if this helps. If it does not, then see how far the tremolo signal is going.

You will not need a scope to trace such a low-frequency signal. Put your voltmeter on the plate or cathode of the tremolo oscillator tube, and set the speed control to its lowest point; this will be only 1Hz or so. You will be able to see the oscillations—the meter needle will move back and forth. If it remains steady, the circuit isn't oscillating.

In all oscillator circuits, failure to oscillate is due to one of three things: (1) a bad tube or transistor, (2) wrong supply voltages, or (3) the failure of some part in the feedback loop—unless the output signals get back to the input in the right phase, the circuit will not oscillate. After you have checked the tube by substitution, check the plate voltage to make sure it is all right. If it is not, then find out why—open plate resistor, open depth or strength control, etc. If there is plate voltage but still no oscillation, check all of the capacitors in the feedback loop. If one of them is open, it will open the loop.

A leaky capacitor here will change the phase-shift angle; the oscillator will work, but on the wrong frequency. So, if it is working much too fast or slow, check the capacitors in the feedback loop. Also check for any drift in the value of the resistors; they are equally important in making the thing work on the right frequency. Use the same servicing methods here that you did on the amplifier stages earlier; there are only a few parts in the circuit, and if the oscillator does not work, then some component must be defective.

If the oscillator is working as shown by the swinging of the meter needle, but there is no tremolo effect, signal trace the varying voltage. Start at the plate where the signal is all right, and follow it through the various parts until you find where it is being blocked. In the circuit of Fig. 2-10 the tremolo signal comes from the 12AX7 oscillator, through the 250,000-ohm depth control, a 750,000-ohm resistor, and a .1-μF capacitor, and is applied to the screen grid of the 5879 second preamplifier stage.

You can follow the voltage swings up through the control and the 750,000-ohm resistor, and even through the capacitor onto the screen grid itself, if they are very slow. Failure of any part in the circuit will show up right away. For example, if the .1-μF capacitor gets leaky, it will change the screen grid voltage. There is about 90 volts on the plate of the tremolo oscillator and only 20 on the 5879; a leak in the capacitor would result in the screen grid voltage going above normal. Incidentally, if you get a peculiar action in this circuit—the tremolo is working but isn't working right, or you can't get enough depth or strength—check that 6.8-megohm resistor. If it

has increased in value, it will reduce the screen grid voltage and upset the action of the tremolo. A key clue here will be the fact that without any tremolo being used, the amplification of that channel is very low, since there is no screen-grid voltage at all. It can even work very peculiarly—you may not be able to get any signal at all through that input unless the tremolo is turned on. Always suspect any big resistors you may find in these circuits. Many servicemen have a habit of thinking, "Oh well, 6.8 megohms. What if it does drift a little off value? It's so big that it won't make any difference!"

This is not so. Most of the very large resistors are critical, especially if they are used in a B+ voltage distribution circuit as this one is. When they do drift, they seem to want to increase in size most of the time. Many of these have been checked and found to be up to 10, 12, or even 20 megohms in value, when the color code stated plainly that they were supposed to be 3.3, 6.8 megohms, and so on. Don't ever overlook these resistors—that just might be the trouble.

VIBRATO

A true vibrato is very hard to get electronically, so all manufacturers use the mechanical type; a tailpiece on the guitar can be moved up slightly back and forth by a long lever. Troubles here are mechanical. Frankly, the author has encountered very little trouble in this assembly, but it is always possible. One of the bearings or suspension brackets can wear or become loose, and this would lead to some odd troubles when the vibrato lever was moved.

REVERBERATION CIRCUITS

Troubles in the reverberation units are typical—plenty of signal (volume), but no reverb effect at all. Check tubes, voltages, capacitors, and resistors, and follow the signals through the reverb unit just as you would through any other amplifier. Leaky coupling capacitors in tube units can cause a very odd distortion: the straight signal will not be distorted but the delayed signal will. Open electrolytics in transistor units can cause trouble; so can shorted transistors. Check base and emitter voltages very carefully on transistors to make sure that the bias is all right. Since this is only a few tenths of a volt, incorrect bias can be easily overlooked.

The reverberation unit springs must be left severely alone. Because of their construction, they can seldom be repaired successfully in the field. There are only two things that go wrong with these: failure of the transducer or failure of the pickup unit. In either case the defective unit must be replaced, which involves taking the springs out and putting them back later. This inevitably causes them to get stretched, and their delay time changes very drastically. Since no service shop has the facilities for testing delay times in milliseconds, the best thing to do with a defective reverb unit is replace it with a new one. Some manufacturers have service facilities where the bad unit can be sent back for repairs.

Reverb units are easy to test, so you can be sure that the unit is definitely defective. Simply feed a signal into the grid of the reverb input tube, and check to see if it is coming through the reverb unit and is getting to the grid of the reverb output tube. If the circuit is confusing, the direct path circuit can be broken by disconnecting a resistor. That way you know that any signal you get must be coming through the reverb unit itself. Broken wires are not uncommon, and these, of course, can be repaired; as long as the delay springs are not disturbed, you can do anything you have to.

TEST EQUIPMENT FOR SERVICING GUITAR AMPLIFIERS

You won't need any "specialized" test equipment for servicing guitar amplifiers. Ordinary "shop-type" test equipment will do everything we need. The average service shop has practically everything necessary. There are a few pieces of auxiliary equipment such as dc ammeter, Variac, wattmeter that will be very useful, but these aren't expensive.

Tests on these amplifiers will be confined to reading ac and dc voltages and current, signals, and resistance. You'll need a source of test signals, for the signal-tracing tests.

AC and DC Voltmeters

You'll need an instrument to read ac and dc voltages. For this, you can use one of two types—the electronic volt-ohmmeter which can be a vacuum-tube voltmeter, or a solid-state vom, generally using FET's. These instruments have a very high input impedance, which means that they load the circuits under test very little. For our purpose, either type will do. Servicemen in general refer to them all as "vtvm's," so that's what we'll call them from now on.

Many shops use the vom. This is a "straight" meter, without electronic amplification, as used in the vtvm's. Voltage and resistance ranges will, in general, be about the same. The main difference is that the vtvm's will not be damaged if connected to voltages higher than the full-scale setting. The vom will be damaged. For best results, you can use the vtvm for all ac or dc volt-

ıge measurements, and use the vom mainly for current 'eadings. These have dc current ranges from a few mil-iamperes up to several amperes. One handy service ɔrocedure is to use the vom to read the current in a ;tage under test, while taking voltage readings with the /tvm at the same time. For example, while setting the :ollector current and base bias voltage on a high-power ɔutput stage; two meters make this job much easier. Many men keep a single high-range dc current meter ɔn the bench, for current testing.

The Oscilloscope

For all signal testing, the oscilloscope is by far the most useful instrument on the bench. It can do things that none of the rest will. The scope will not only show you the peak-to-peak voltage of the signal, but it will also show you the *waveform*. So, this is the only instrument that can be used for finding the cause of distortion. Any change in the signal waveform means distortion of the output; clipping, unequal amplification of both halves, and many other faults can be quickly and accurately spotted with the scope.

With only two tests, you can tell whether a given stage is passing a signal, or amplifying it as much as it should. For signal-tracing tests, to locate a dead stage, the scope will get results in about one-fourth of the time needed with all of the rest put together. Simply touch the probe to the input, then the output of a stage, and note the difference between the amplitude of the two signals. If you have signal at the input, but none at all on the output, that stage is dead. Put down the scope probe and start taking dc voltage measurements; you have found the source of the trouble.

This is all audio work, so an expensive wideband scope is not necessary. Many shops have perfectly good, but old, scopes which won't work on color TV, etc.; they will be perfectly good for audio, since the highest frequency we'll be working with will be about 20 kHz.

The scope can make one test that no other can make. With a quick jab of the scope probe on a filter capacitor in the dc power supply, it can locate the cause of hum, oscillation, feedback, etc. If you see any kind of *signal* on the dc power supply circuits, look out! This means trouble.

The Audio-Frequency Signal Generator

The preceding instruments have all been what we might call "output" testers. They read the dc supply or output of a certain circuit, dc voltages, waveforms, etc. To complete the setup, we need an instrument that will give us a known source of *test signals*. For the best results, we need a single-frequency sinewave audio signal, which can be controlled in both frequency and amplitude.

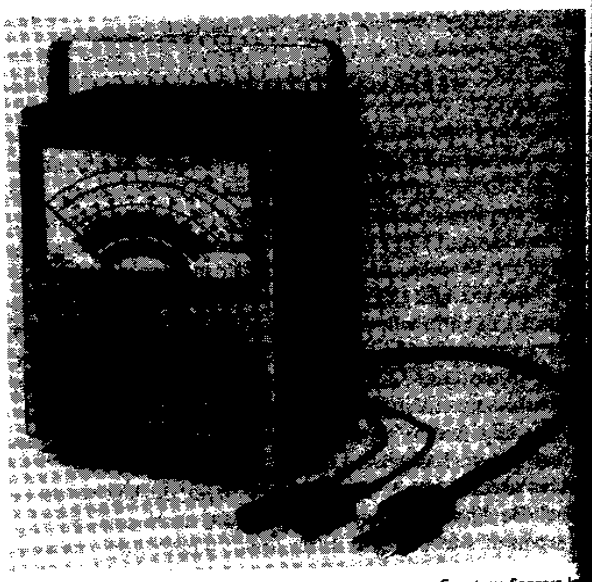
This means some kind of audio-frequency signal generator. The typical instrument will cover a frequency range from 20-30 Hz up to 20 kHz, and have a maximum audio signal output of about 3 to 4 volts. Calibrated attenuators will reduce this to a very low level; for testing sensitive amplifiers, we need a level of about 50 millivolts. The audio signal generator does not have to be an expensive, high-precision type, but should have an output with less than about 3% distortion. This isn't hard to get; there are a great many makes and models to choose from, within a moderate price range.

The Auxiliaries

There are other things, some of which wouldn't be called "test equipment" alone, but which can be very useful in speeding up the work of getting the guitar amplifier back into good shape. These are not expensive, and will pay for themselves in a short time.

The *Variac*

A variable-output ac power-supply transformer, usually called a *Variac*, is extremely useful. With this, you can adjust the ac line voltage supply to the amplifier to any level from a few volts up to 135-140 volts, well above the normal line level. Later on, we'll show you a very useful test you can make with this instrument, one which can save you the entire cost of the *Variac* on one job.



Courtesy Sencore

Fig. 4-10. Single unit multirange wattmeter.

Dummy Loads

For making full-power tests of guitar amplifiers, especially the very high powered types, a suitable dummy load must be connected in place of the speakers. (You simply can not turn loose up to 300 watts of audio power inside a small shop. It may break the windows!) So, you need a high-wattage load resistor, which can be adjusted to match the rated load impedance of the amplifier being tested, and carry the power to be dissipated.

You can get high-wattage, low-resistance resistors from surplus, or make them up of combinations of ordinary stock units. Ohm's law will give you the values needed. For example, ten 10-watt resistors in parallel will handle 100 watts of power. (ten 40-ohm resistors, paralleled, equals 4 ohms, and so on)

The Wattmeter

A wattmeter can be very useful, especially in dc power supply testing. By reading the actual power being drawn by the amplifier, it will tell you instantly if there is anything out of order. This will detect short-circuits, open circuits, high leakages; anything abnormal, instantly. Fig. 4-10 shows a typical single-unit, multirange wattmeter. No special connections are needed; you simply plug the amplifier into the panel outlet of the wattmeter, and turn it on. The actual power drain is read on the meter.

Later on, as we go through the various test procedures, we'll show you how to use these instruments, singly and in combination, to test any part of any circuit, and to make all necessary test readings to insure the best performance from the amplifier.

Chapter 5

The Power Supply

No amplifier can work unless the power supply is providing the correct voltages and currents. Be sure that it is all right—check it first in every service job. It is the part of the circuit that works the hardest, so it will have the most troubles.

Some typical circuits were discussed in Chapter 3. Almost all of the amplifiers now use the power transformer circuit. However, you will find the transformerless type occasionally, and it is simpler, so it is listed first.

THE TRANSFORMERLESS CIRCUIT

Fig. 5-1 shows the circuit of a typical transformerless power supply with the parts named. It is simple but effective. The rectifier converts ac into a pulsating dc by allowing only one-half of the voltage to get through—those half-cycles which make the anode (plate) of the rectifier positive. These half-cycles of voltage charge the input filter capacitor up to the peak value of the ac line voltage, which will be about 150 volts with a 117-volt line. This drops slightly because of the load current drawn by the amplifier, and the usual dc output voltage, under load, will be about +135 volts as shown.

What kind of troubles can develop in this circuit? One is capacitor failure. Electrolytic capacitors can dry out and become open. If the input capacitor opens, the voltage will drop very badly—to between 40 and 50 volts in most cases. The input filter capacitor acts as a reservoir; it holds a charge as the half-cycles of voltage are fed to it from the rectifier. If it will not hold a charge (if it is open), then the voltage has no place to be stored, and the output falls very badly. This filter is sometimes called a reservoir capacitor for this reason.

A quick test for an open input electrolytic is as follows. If you find a circuit with very low voltage at the rectifier, simply bridge another capacitor across the filter input to take the place of the one you suspect to be open. Hook a dc voltmeter across the output. If the voltage jumps back up to normal when the new capacitor is shunted across the old, the original one is definitely bad; replace it.

If the output filter capacitor opens, you will notice very little difference in the output voltage, but there will be a noticeable increase in the hum. The main job of this capacitor is to take out the last of the ac ripple and leave the B+ as fairly smooth dc. If it fails you will hear a loud hum. The same test as before is used—bridge another capacitor across it. Listen to the hum. If the old one is bad, you will hear the hum drop to an almost imperceptible level. Again, replace it.

Most power supplies have dual filter capacitors that is, both capacitors are in one can. If one fails always replace both of them. The condition inside the can that caused one to fail will quickly cause the remaining one to go, too. Don't take chances—always replace the complete unit if any section of a multiple unit capacitor fails. You will find as many as four in a single can in the larger amplifiers; change them all for safety.

The rectifiers can fail, also. If selenium rectifiers—the ones with the large cooling fins—are used, the can get weak and develop too much voltage drop across the rectifier itself. This, of course, drops the B- output voltage. You will naturally suspect the input

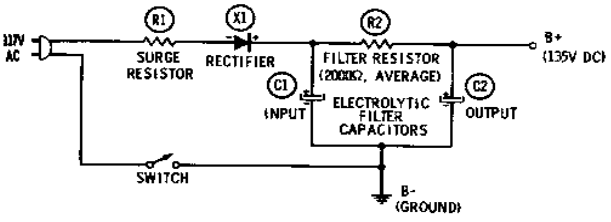


Fig. 5-1. Transformerless power supply.

filter capacitor, for this is a more common trouble; when bridging the old filter does not bring the voltage back up, check the rectifier.

You can bridge a selenium rectifier just as you did a filter capacitor: connect a new rectifier, being very careful to get the right polarity (+ to +, − to −), directly across the suspected one, checking the output voltage at the same time. If the new rectifier brings the voltage back up to normal, replace the old one.

If the much smaller silicon rectifiers are used, you will not find this kind of trouble. Silicons are made in various shapes, but have no cooling fins. You can always identify them by their very small size. They will never get weak and show low output voltage because of their construction. When they fail, they are like the little dog—they die all over. In other words, they short out completely.

A shorted rectifier lets the ac line flow to the input electrolytic capacitor. Since an electrolytic is a very effective short circuit to ac, a large current will flow, and the surge resistor will blow. As a matter of fact, that is part of its job. These are specially built wirewound resistors or chemical resistors, and they are designed to blow out just like fuses if there is a current overload. They are called fusible resistors. If a surge resistor does burn out, be sure to replace it with a resistor of the same value and type, for it is designed to give the power supply circuit exactly the right amount of protection against overloads.

You will find short circuits in the loads too. If a bypass capacitor or one of the power tubes shorts out, you may find a blown surge resistor. Always check carefully before replacing rectifiers and/or fusible resistors to find out what caused the fuse to blow. Make ohmmeter tests from the B+ point to B−, directly across the filter capacitors. If you get less than about 12,000 to 15,000 ohms, disconnect the B+ circuit from all loads and recheck. This amount of resistance is normal across one of these power-supply circuits; it is the leakage resistance of the very large electrolytic capacitors used. By reversing the ohmmeter prods, you will find that one way there is a much higher resistance; this is because you have hooked up the ohmmeter (with its built-in battery) with the right polarity, and the electrolytics will not show as much leakage current. The 12,000-ohm reading is a minimum; if you get less than this, disconnect parts, one at a time, until you find which one is causing the trouble.

If you get an amplifier where you cannot locate the trouble from the ohmmeter reading, disconnect the load, leaving the B+ supply all by itself, and turn on the amplifier. If you get the normal voltage reading, or quite a bit more (due to the lack of loading), the power supply is all right. The short is in some of the load circuits, and you have eliminated the power supply as a suspect. Use the process of elimination again to find the defective component.

Electrolytic filter capacitors used in transformerless power supplies are very large. You will find values like 80 to 100 μF in the input, and 60 to 80 μF or more in the output. These will have working voltages of 150 volts dc, and they will usually be in the same can. When you replace a filter, be sure to get as close to the original values as possible. However, filter capacitors are not too critical; you can change from the original values as long as you use larger ones. For example, 100 μF is a good replacement for 80 μF, but 60 μF might allow some hum to creep in.

Watch out for output filter capacitors with a high power factor. This happens when the capacitor gets a little too old and starts to dry up, losing some of its capacitance. Since the filter capacitor also acts as a bypass capacitor for all other circuits in the amplifier, this can cause an increased hum level, and can even allow the amplifier to go into oscillation or motorboat (a slow "put-put-put" oscillation, sounding very much like an old motorboat).

In a few cases, to get a positive check on filters with a high power factor, you will have to disconnect the old capacitor entirely and substitute a new one across the terminals of the circuit. Sometimes the old capacitor develops a fairly low series resistance, and this can upset the tests. To make sure the old filter is bad, substitute a new one.

TRANSFORMER-POWERED CIRCUITS

Most of the larger electric guitar amplifiers use power transformers; this is done because much higher voltages can be obtained, and the always-present shock hazard in the line-connected circuits is eliminated. Fig. 5-2 shows a typical power-transformer B+ supply with parts named.

Notice that the filter system is like the one used on the transformerless type, except a filter choke is used in place of the resistor. The choke gives much better filtering action, and has far less voltage drop. The

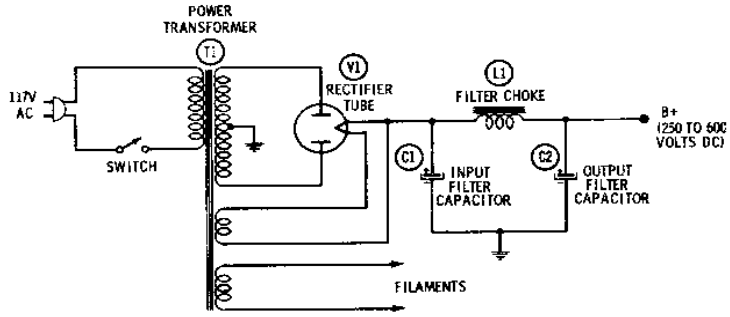


Fig. 5-2. Full-wave power supply using a power transformer.

average dc resistance of a filter choke is about 40 to 50 ohms instead of the 2000 ohms of a filter resistor.

When a choke is a part of the filter, smaller filter capacitors can be used without reducing the filtering action. You will find sizes like 20 to 30 microfarads in the input and 40 to 60 microfarads in the output. The schematic (Fig. 5-2) is for a full-wave rectifier; both halves of the incoming ac voltage are used. There is no 60-Hz hum in this power supply. By folding up the other half of the ac cycle, there results a basic 120-Hz hum or ripple component. Remember this: it is used in further troubleshooting tests. After a little practice you will be able to tell the difference between 120-Hz hum and 60-Hz since the latter is definitely lower pitched and smoother. Fig. 5-3 shows the folding up of the ac voltage in the full-wave rectifier and the 120-Hz hum component (ripple) at the output.

B+ output voltages are much higher in transformer power supplies. You will find from 250 volts to 450 volts in common use, and in some of the very high powered amplifiers there is up to 600 volts dc output at the filter. So, filter capacitors must have a much higher working voltage rating; in such circuits never use units with less than 450 working volts. Check the voltage shown on the schematic or measure it in the actual amplifier circuit, and use a capacitor that will stand it. A good rule is to use a capacitor with a working voltage at least 100 volts above the normal voltage.

Capacitor troubles are the same in transformer as in transformerless power supplies. An open input filter capacitor causes the B+ voltage to fall off considerably; in a full-wave circuit the drop is to about half the normal voltage. Test for it in the same way: Bridge a capacitor known to be good across the suspected unit, and see if the voltage comes back up to normal. Always replace the whole thing when one section of a multiple unit is bad.

Bad output filter capacitors will cause hum, oscillation, or both in the amplifier. Use the same check as before. Bridge with a good one and listen to the hum. Open input filters ordinarily do not cause as much increase in the hum level as open output filters. However, this is not always true, so check both input and output capacitors if you have too much hum.

REPLACING ELECTROLYTIC CAPACITORS

If you do find an open electrolytic capacitor, you will have to replace it. Many amplifiers use multiple units, having as many as four sections in a single can. There is a trick you can use on this to save time. Get a replacement capacitor as near to the same value as possible and with the same type of mounting. Leave the old unit in the circuit until you have done the following.

Check the position and especially the working voltage of each section of the new units. Many will have three high-voltage capacitors and one low-voltage unit

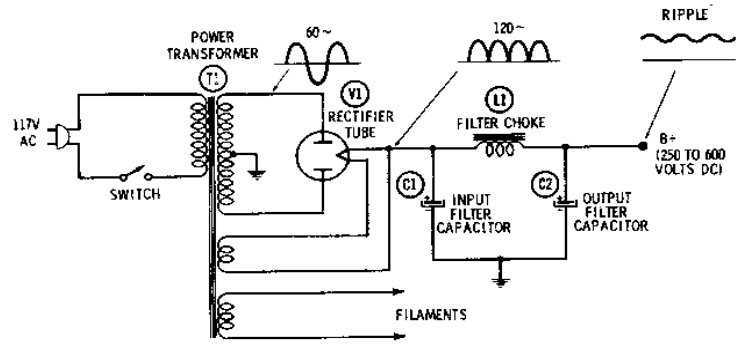


Fig. 5-3. Power-supply waveforms.

(for cathode bypassing) in the same can. You do not want to hook up the 50-volt cathode bypass to a 400-volt circuit—the capacitor has a tendency to explode! Check to make sure just which ones are high-voltage types. All sections are coded by small punchouts in the fiber insulator on the lug end: triangle, square, half-moon, and plain. The values corresponding to each mark are stamped on the side of the can—the capacitor size and rated voltage.

Make a little chart of the wire colors fastened to each lug. Somebody may come in and interrupt you, and you may not get back to this amplifier for hours. This keeps you from losing track. The cathode bypass often has only one wire on its lug, and it is yellow if the manufacturer has followed the standard color code for such wires. This is handy as a locator.

Now you are ready to change capacitors. Instead of unsoldering all the wires (and there may be as many as 4 or 5 on each lug) simply clip lug and all off with diagonal cutters and bend them up slightly. Take the old capacitor out, and mount the new one, trying to get it placed so that each lug comes out as close to the one it is replacing as you can.

Finally, bend the old lugs with their group of wires down and lap them alongside the lugs on the new one. Solder each one firmly in place, and there you are.

SHORT CIRCUITS

Short circuits in the B+ supply network are a common trouble. Looking back at Fig. 4-3 you can see how the B+ voltage is fed to all tube plates and to screen grids (if they are used). There will be numerous bypass capacitors throughout the network; they are not shown in Fig. 4-3 to simplify the drawing. However, they are a source of a lot of the shorts, so they must be checked. Fig. 5-4 shows one bypass capacitor circuit. This may be the screen-grid bypass of a pentode driver tube, for instance.

What happens if the bypass capacitor suddenly develops a very low leakage resistance? Current flows through the capacitor where none should flow at all, adding to the normal current through the dropping resistor. The resistor promptly gets very hot, giving a good clue to the nature of the trouble. Look for hot resistors—not just warm or even uncomfortably hot to the touch (some resistors normally run that hot). Look for the ones that are smoking. Resistors on which the color-coding paint is burning off are definitely overloaded. There are several tests that point directly to the trouble if you find a "hot one." First, turn the amplifier off, and check the resistance readings on both sides of the resistor. Normally, you will get a fairly low resistance on the B+ side of the resistor since you are reading through the leakage resistance of the electrolytic capacitors in the filter. However, going to the load side of the resistor (the screen grid), you ought to find the normal value of the screen dropping resistor, plus the first reading.

If you get approximately 25,000 ohms on the B+ side and about 5000 ohms on the load side, look out. Disconnect the capacitor, and take the second reading. Also check the resistance from ground to the open end of the capacitor itself; in fact, this is usually the first test made. If you get any resistance reading at all across the capacitor, it is bad. Replace it.

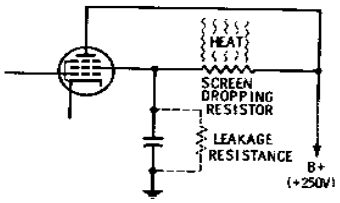


Fig. 5-4. Capacitor leakage overheats dropping resistor.

The axiom for troubleshooting in the RC circuit is: Always check for a short on the load side (not the B+ side) of a hot resistor. This is a simple and obvious test, but it is surprising how many men will not make it correctly. You will find RC networks used all over the amplifiers, expecially in B+ circuitry. Take the time to learn how to check them out correctly, and you will find many of the troubles very rapidly.

LOW B+ VOLTAGES

Sometimes you will find an amplifier that is very weak—not enough volume. This is a common trouble, so it deserves close study. The first thing to be suspected, as always, is the tubes. Replace the rectifier tube and the power output tubes, because these are the hardest working tubes and the most likely to be weak. If this does not help enough, replace the other tubes, one at a time. This will cure most weak amplifiers, since weakness is caused by tubes more often than by anything else.

Tubes are not the only cause, however. If tube replacement fails, check the B+ voltage; this is the next most common cause. Measure the B+ to see whether it is up to normal. If you do not have a schematic, check the ac voltage on the rectifier tube plates (one plate to ground, not plate-to-plate) and add a correction factor of about 10 to 15%, which is the normal amount the rectified output voltage is above the rms ac input. A plate-to-ground measurement of 320 volts ac should result in a rectifier cathode output of 350

volts to 370 volts dc with load connected. The most likely power-supply troubles have been discussed previously.

If the B+ is up to normal (and it must be before you go any farther with this testing), start looking for something off in the rest of the circuits. Most likely suspects are plate load resistors that have increased in size in any of the voltage-amplifier circuits. If a 100,000-ohm plate resistor rises to about 750,000 ohms, it cuts down on the plate voltage of that tube and the amplification. Check them against the color-coded value printed on each one.

A good quick check for off-value load resistors is the plate voltage. Make a fast run through the whole amplifier, looking to see if all plate voltages are about normal. After a little practice you will be able to do this very quickly since these are not critical (within about 10 to 15%). For instance, if you see a stage with a 100,000-ohm plate resistor and you know that the supply voltage is about 175 to 200 volts, then you should expect to find about 100 to 200 volts on the plate. So, if your voltmeter swings up to about 100 volts, don't even wait for it to stop; keep going. This isn't the one you're looking for! What you want to find is the stage with the right dc voltage on the supply end of the load or dropping resistor, but no voltage at all on the load end, or only a small fraction of the supply.

Watch out for filter resistors, especially those secondary filters used to isolate preamplifier stages from the rest of the amplifier. Resistor R1 in the schematic of Fig. 4-2 is an example. If this increases in value, all plate voltages fed from the load end of this resistor will be low, and so will the gain and volume. Leakage in the electrolytic capacitors used to filter the load end of these resistors also causes low supply voltage. In this case the resistor will be very hot, giving a good clue to the source of trouble.

If the low volume complaint is also accompanied by some bad audio distortion and the tone is very mushy, look for a leaky coupling capacitor between two stages. In fact, most really good technicians make it a practice to check the grid voltages on all voltage-amplifier tubes. If you find even the slightest trace of positive voltage (even half of a volt), check that coupling capacitor; it is probably getting ready to break down. Always use replacement capacitors with ample voltage ratings. No coupling capacitor should ever have less than a 600 working-volt rating to get a low leakage characteristic. Some of the cheaper amplifiers will have 400-volt capacitors installed as they come from the factory; these ought to be replaced by the sturdier 600-volt types whenever possible for longer service life.

TESTING POWER TRANSFORMERS

Now and then you get an amplifier with the power transformer smoking or bleeding wax from the bottom. This means one thing definitely: The power transformer has been very badly overheated. However, it does not necessarily mean that it is burnt out.

There are two things that happen to power transformers that cause overheating: (1) an internal short in the windings, which is hopeless since it can't be repaired, and (2) an external short such as a shorted filter capacitor or rectifier tube that has overloaded the transformer and made it overheat. In the latter situation, it is still good unless it has gotten so hot that the insulation inside has broken down.

Here is how to find out. Take off all loads from the transformer: take out all of the tubes, and if the amplifier uses silicon or selenium rectifiers, disconnect these. With all external loads removed, a good transformer will draw practically no current at all. When disconnecting leads for testing, don't unsolder them; clip them off near the terminals, leaving a short piece of the original wire on the terminal so that you can tell the color code. If a new transformer is necessary, you can disconnect the rest of the lead and follow the color coding when installing the new unit. This makes the job faster.

If you have a wattmeter, plug the transformer into it, and apply power. If the transformer is all right, it will not draw enough current to give a reading. The only input current that flows in this condition is the iron loss; this is never more than about one or two watts in a well-designed transformer. However, if you see as much as 25 to 50 watts indicated and you are sure that all external loads have been removed, the transformer is internally shorted and must be replaced.

You can make up an emergency wattmeter that will give you the same answer; Fig. 5-5 shows how. It is not precise, but it will tell you what you need to

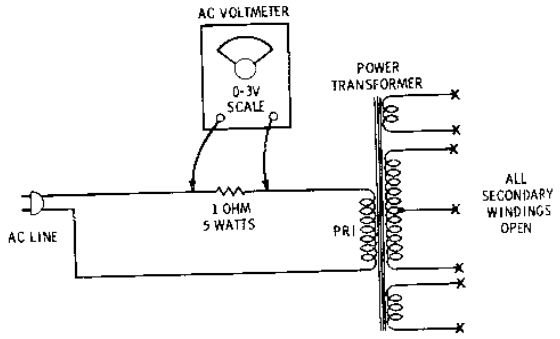


Fig. 5-5. Emergency wattmeter circuit.

know. Hook a noninductive 1-ohm resistor of about 5 watts in series with one side of the input ac line to the primary. Put an ac voltmeter across the resistor, and you can read the voltage drop, which is directly proportional to the ac current through the resistor. Any appreciable current being drawn by the transformer will give you a reading. A 1-volt drop across a 1-ohm resistor means that 1 ampere of current is flowing; 1 ampere of current at roughly 100 volts (approximate line voltage) equals 100 watts of power being used by the transformer. Power is figured by multiplying current times voltage.

There is still a third way. Take off all loads and turn the amplifier on; let it sit on the bench for about 10 minutes. If the transformer gets hot, it is shorted internally. If it is badly shorted, you will know it right away; you will hear it hum inside, and smoke will start to come out very shortly.

Replacing Power Transformers

To make replacements faster after the old transformer has been definitely proven bad, leave it on the chassis until the new transformer is at hand, ready to install. If the old transformer uses nonstandard color coding, trace the circuits (filament, plate, etc.) and make up a scratch-paper list of the colors and where each one goes. This is a great time saver.

If you cannot get a replacement transformer from the manufacturer that is an exact duplicate or if you do not have the time to wait, you can figure out what size is needed. This requires that three things be determined: the electrical ratings of the transformer, the physical size, and the shape and kind of mounting used. This information is not hard to find. The schematic designates what ac plate voltage is used. If you know approximately what the B+ voltage is, you can take 0.9 or 0.95 times it and use the closest available replacement. For example, a 350-volt B+ probably has a 320-volt ac input to the rectifier. The current rating is determined chiefly by the number and type of output tubes used. Take, for example, an amplifier with two 6V6 tubes, in a push-pull output stage. Referring to a tube handbook, two 6V6s draw 70 mA of plate current and 5 mA of screen current with no signal input, for a total of 75 mA. When you add about 50% to allow for maximum signal input, current through other tubes, and a safety factor, a current capability of about 120 mA is indicated. The high-voltage secondary will be rated to show this: for example, "320 Vac, ct (center-tapped), at 120 mA" or "200 mA," or whatever is necessary. You can always use a higher current rating, since this is the maximum current that the transformer can supply. Do not go over the peak ac voltage rating, however. If you do, there can be trouble; a higher than normal B+ voltage for the circuit will blow filter capacitors, bypass capacitors, and so on. Stick within about 10 volts of the original. If you miss it, take one rated 10 volts lower rather than 10 volts higher.

Filaments are easy; just add up the filament currents of the tubes. Most amplifiers use all 6-volt tubes, or 12-volt tubes with the heaters connected for 6 volts. Get a transformer with a 6.3-volt winding at so many amperes. For instance, seven tubes drawing 0.3 ampere each add up to 2.10 amperes, so a transformer with a 6.3-volt winding rated at 3.0 amperes (safety factor) would be needed.

If one 5U4 rectifier tube is used, the transformer must have an additional filament winding "5.0 volts at 2.0 amperes." If two 5U4s are used, the voltage will be the same but the current must be doubled (to 4.0 amperes), and so on. If dry rectifiers are used, there will be no need for this filament winding on the power transformer.

If a bridge rectifier made up of silicon or selenium rectifiers is used, the high-voltage winding will not need the center tap used on full-wave tube rectifier circuits since the B−, or negative return, for the power supply is taken off at one terminal of the bridge. If the transformer you get has a center tap on this winding (probably a red/yellow wire), simply tape it up and forget it.

Get a transformer with the same physical size and mounting if you can; it makes mounting the new transformer a lot easier. However, if you cannot get the right mounting, other types are simple to convert, though it takes time. Get long bolts, brackets, etc., and fasten the new transformer solidly to the chassis; that is all you need to do. Fortunately, in guitar amplifiers there is usually plenty of room above and below the chassis because of the design of the cabinets used.

TRANSISTOR AMPLIFIER POWER TRANSFORMERS

The only difference between power transformers in transistor amplifiers and tube types is the voltage and current ratings. If you have a schematic which shows the highest dc voltage output from the power supply, you can use the formula previously given to find the ac voltage needed. However, you may not find the output current ratings given.

These can be figured, roughly, from the total wattage output of the amplifier, using the "E × I" formula of Ohm's law. If the amplifier has fuses in the dc supply lines (they all should have; some do not), you can use the fuse rating as a rough guide. For example, if an amplifier has a 2-ampere fuse in the dc

supply line to the output stages, you can safely assume that the power transformer should be able to supply a maximum current of at least this much. For safety, try to get one with a 2.5-ampere rating on that winding; with this, the fuse will blow, but the power transformer itself shouldn't be damaged.

Watch out for center-taps. In the dual-polarity voltage types, a bridge rectifier will be used with the center-tap of the secondary winding grounded. In the single-polarity types, with bridge rectifiers, a center-tap is not needed. If the transformer has one, you can tape up this lead and ignore it. In the last instance, your ac voltage would be read from end to end of the secondary winding, not from ct to each end, as in the first.

VOLTAGE REGULATORS

In some high-powered tube amplifiers, you may find voltage-regulator circuits. These are used in the plate and screen-grid circuits of the output tubes and sometimes the drivers to keep the B+ voltage the same all the time. If it changes too much under heavy loads or high volume, there will be distortion. Fig. 5-6 shows a typical circuit.

The basic principle of this is simple. The B+ supply is connected directly to the plates of the high-power output stage so that it is not regulated. Another tube (the voltage regulator) is connected in series with the screen grids of the power output tubes and other stages ahead of this point. A tube is chosen for this that is capable of carrying the total currents of all regulated stages. The B+ voltage supply goes to its plate, and the other tubes are all actually connected to its cathode.

This circuit puts the plate resistance of the voltage-regulator tube in series with the stages using the regulated B+ supply. The tube acts as an automatically variable resistor. If the supply voltage goes up, the plate resistance automatically increases to cause a greater voltage drop; the regulated output stays the same. If the voltage goes down, the opposite happens; the regulator tube reduces its plate resistance, taking less of the voltage.

How does this happen? Notice that the control grid of the 6V6 regulator is connected to a voltage divider of a 150,000 and a 100,000-ohm resistor in series; the top of the divided is B+, the bottom is ground. The grid always has two-fifths of the B+ as bias at all times. The bias voltage controls the amount of plate current drawn by the tube, and thus controls the tube plate resistance. If the B+ voltage rises (goes more positive), then the bias rises with it, and the tube draws more current, increasing its plate resistance, and vice versa.

Tube voltage-regulator circuits are not hard to service. Check the voltage input and output of the regulated stages; if it is within limits, the regulator is probably all right. If it is quite high or low, then check the regulator. Replace the tube first, and, if this does not help, turn the amplifier off and measure the resistance of the voltage-divider resistors. These are pretty critical since the ratio between the two determines the amount of bias and the action of the regulator tube. If one is replaced, the other should also be replaced at the same time. Use at least 10% tolerance resistors for this; 5% is even better.

To test these resistors for heat drift, hook an ohmmeter across each one, and heat it up by holding the tip of a hot soldering iron on the body of the resistor until it is good and hot. If the resistance changes more than a very few percentage points, replace it. They must never drift over 5%. Use high-quality resistors, and always use at least the same wattage rating as the original.

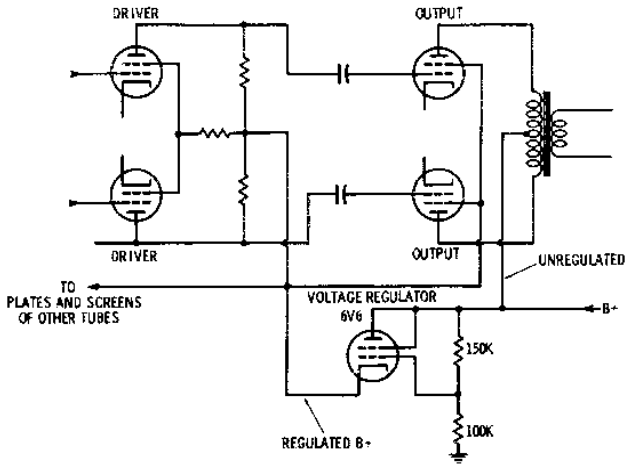


Fig. 5-6. Voltage-regulator circuit.

Voltage-Regulator Tubes

There are several tubes made especially for voltage regulation. Different regulated output voltages (75, 90, 150 volts, etc.) are available. They are gas-filled tubes—basically diodes. The circuit of Fig. 5-7 shows how they work. Until a certain value of positive voltage is applied to the plate, the tube does not conduct current at all. Once this value is exceeded, however, the tube fires and begins to conduct heavily. To use it for voltage regulation, a resistor is placed in series with the tube, connecting the plate to the full B+ voltage.

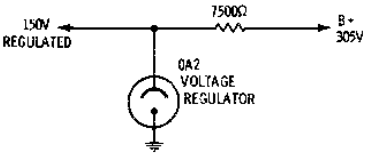


Fig. 5-7. Voltage-regulator tube circuit.

This circuit is used in several commercial amplifiers. When the voltage on the tube plate reaches the ionization value, the tube fires. This acts as a partial short across the circuit, and the tube draws current from B+ through the 7500-ohm resistor. This current is enough to cause a voltage drop across the resistor, so the regulated output drops to the rated value—150 volts with a type OA2 tube.

If the B+ voltage rises above normal, the OA2 conducts more current and a higher voltage drop appears across the 7500-ohm resistor. The output voltage stays at 150 volts. If the B+ voltage falls below normal, the OA2 tube conducts less current, and the voltage stays at 150 volts just as before. Voltage-regulator tubes will hold the voltage constant over a range of 5 to 30 mA of current through the tube itself, taking care of any normal variation in supply voltage.

If the voltage at the output of a VR tube circuit is not correct, replace the tube, and check the dropping resistor.

Voltage Regulators in Transistor Amplifiers

In quite a few of the better amplifiers, you will find voltage-regulator circuits used. There are three major types, but you'll find only two of them in common use. The simplest, and the most popular, is a simple zener-diode regulator. This is normally found in dc supply circuits feeding small-signal stages, special effects, etc., to avoid gain fluctuations, and reduce feedback. Fig. 5-8 shows the schematic of such a regulator.

The action of this circuit is very simple. A zener diode is a special type diode, deliberately designed to go into "avalanche" conduction, sometimes called "reverse breakdown," when the dc voltage across it exceeds a certain value. Each zener diode has a certain "zener voltage" at which it goes into conduction, in the reverse direction. In the circuit of Fig. 5-8, if the zener is a 12-volt type, the unregulated dc supply might be say 14 volts. The resistor is just big enough to cause a small voltage drop under normal current loading.

Now, this will give us a regulated 12-volt supply. As long as the supply voltage is above 12 volts, the zener will be in conduction, and "clamp" the dc output voltage at no more than 12 volts. Of course, this is a sort of one-way action; the zener will keep the

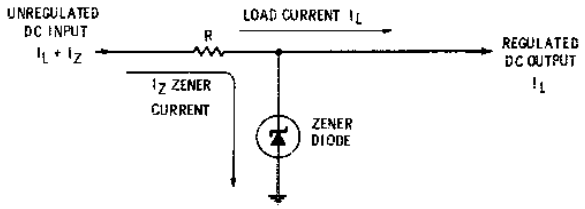


Fig. 5-8. Simple zener-diode voltage regulator.

output voltage from going *higher* than 12 volts, but if the supply falls below 12 volts, it will stop conducting and have no effect at all.

The wattage rating of the zener is determined by the zener voltage (voltage drop across the zener itself) multiplied by the maximum current which flows *through the diode*, I_z. This is *not* a part of the *load* current, which is determined by the circuits fed from the regulated supply; this is just the shunt current which flows through the diode itself. (As an example, a 12-volt zener which drew 0.5 ampere would be dissipating 6 watts, 12×0.5. So, a replacement zener should have at least a 10-watt rating for safety.) Zeners are available in a great many voltage and wattage ratings, from ¼ watt up to several kilowatts (used in very high power work, not in guitar amplifiers).

Testing the Zener Voltage Regulator

Testing of this circuit is simple. If the dc voltage on the output is below the zener voltage, one of two things is happening. The load circuits are drawing more than normal current, or the zener is leaking. Quick-check; just disconnect the zener. If it is really defective, the dc voltage will go back to a value slightly above normal. If it is still quite low, you have an overload from the circuits being fed from the regulator. Leave the zener off, and trace down the cause of the overload by disconnecting each circuit one at a time.

If the regulated voltage is above normal, the zener is probably open. Check the unregulated dc voltage

on the input. If this is more than say, 2 volts high, check previous dropping resistors, etc. You can read the zener current of any of them, by simply disconnecting one end, and connecting a dc milliammeter in series with it, and turning the power on. From this reading, the actual zener wattage can be calculated.

Transistorized Voltage Regulators

In the tube-type voltage regulator circuit, you can see how the plate-cathode resistance of a vacuum tube is used as a variable resistor for regulation. The collector-to-emitter resistance of a power transistor can also be used as a voltage regulator; transistors are almost ideal dc amplifiers. Fig. 5-9 shows the basic circuit of this type of regulator; this is called a "series regulator." (The other, seldom-seen type, is a shunt regulator; action is the same, but requires greater power loss.)

As you can see from Fig. 5-9, the unregulated dc supply is connected to the collector of a transistor. The regulated dc voltage is taken off the emitter. So, the load current flows through the collector-emitter junction. Like all transistors, the base can *control* the amount of current flowing in the collector-emitter junction. So, if we hold the base voltage at a fixed level, this will also hold the current at a fixed level.

A large capacitor C is connected from the base to ground. When this capacitor is fully charged, it will tend to clamp the base voltage at this value. The zener diode connected to the same place also helps.

The voltage divider across the output is actually a "sampling" circuit. The base voltage of the regulator transistor is determined by the position of the slider on the "Voltage Adjust" variable resistor. By varying this base voltage, the dc output voltage can be set to any desired level, within the range of the supply. If there is a sudden surge or peak of current in the load, the output voltage will try to drop. When it does, the base voltage of the transistor is changed, and it *reduces* the resistance of the collector-emitter junction to let a greater current flow; this holds the output voltage steady. The reverse is also true, of course. If the output voltage tries to increase, due to a drop in load current, the base voltage of the regulator will be changed in a direction which increases the series resistance of the collector-emitter junction, and the voltage on the output is held down.

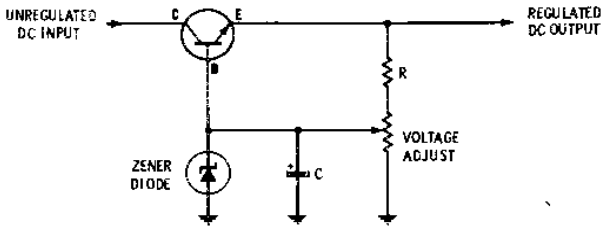


Fig. 5-9. Basic circuit of a transistor voltage regulator.

The limiting factor on this type of voltage regulator is the maximum unregulated voltage of the supply, for the "up" side, and the maximum current rating of the supply, on the "down" side. Within these limits, this type of regulator will keep the output voltage very close to the desired value.

Capacity Multipliers

The same circuit will sometimes be found with the name "capacitance multiplier." There is no difference at all; just a change of title. However, this is just as appropriate. The action of this circuit is so fast that it helps to smooth out even the normal ripple from the dc power supply, as well as any transients that might occur due to line surges, etc. It works like this.

When a pulse of voltage, from the ripple, appears on the unregulated dc input, it would normally go on through and show up on the output. However, this same pulse also appears on the base of the transistor, from the output sampling circuit; this causes the transistor to vary its conduction so as to smooth out the pulse and hold the output voltage absolutely steady.

The big capacitor on the base acts as a clamp, as we said. In effect, the size of this capacitor is multiplied by the dc current gain or beta of the transistor. If the regulator transistor has a beta of 100, and the base capacitor is a 500-μF unit, the equivalent value of this capacitor would look like 500 × 100, or 50,000 microfarads. The zener, too, aids in this action.

Circuit Variations

You will find some series regulators with resistors shunted across the collector-emitter junction. This is done to carry a part of the load current, so that it doesn't all go through the transistor. This lets them use a slightly lower rated transistor as the regulator. The regulation is slightly poorer, but normally adequate.

You will also run across more elaborate circuits. Some of these will have as many as three transistors. The regulator transistor will be in the same place, but an "error amplifier" transistor will be used between the sampling network and the regulator base. In others, a third transistor will be connected between the error amplifier and the regulator base, to get slightly better control action.

Testing the Series Regulator Circuit

These voltage regulators are easy to test. All you need to do is read the regulated dc voltage output. If this is not at the rated value, and the voltage adjust

control will not bring it to the right value, check the unregulated dc input voltage. If this is too low, below the normal value of the regulated output, the regulator can't work.

If the input voltage is normal, but the output voltage is too low, disconnect the loads. If the output voltage goes back up to its rated value, check the action of the voltage-adjust control. If this will vary the output voltage at least 10-15% above and below the rated value, the regulator is probably working, and one of the loads is drawing excessive current. For a definite check on the voltage regulator, disconnect the loads, hook a test load across the output, which will draw something like half the normal output current, and adjust the control to give the rated output voltage. Now, vary the ac line voltage on the input, say from about 100 volts to 130 volts. The regulator should hold the dc output voltage almost exactly "on the nose." If it will not, check all transistors and resistors in the circuit, and see that the filter capacitor is not open, or the zener diode is not open or shorted. Normal input voltage, but zero output dc voltage, could mean that the regulator transistor is open, or that the error-amplifier transistor is bad, causing the regulator to be biased to cutoff. If the regulator transistor has a collector-emitter short, the dc output voltage will rise well above rated value, and there will be no control action at all.

Selecting Replacement Transistors for Regulators

Replacement transistors for defective regulators are not hard to find. The main requirement is the collector-emitter maximum current rating. This, of course, must be well above the normal maximum circuit current that will be drawn in actual service. Use a good-sized safety factor; if this current is, say, 7 amperes, use at least a 10-ampere rated transistor. You will normally find power-transistor types used as series regulators, with driver types used as error amplifiers, etc. Zener ratings will depend on the total power drawn by the circuit, and the desired voltage on the control transistor base. Normally, these will be about 1-watt types; check the specs before making replacements.

PARTS REPLACEMENT IN POWER SUPPLIES

Most of the parts replaced in power supplies will be rectifiers, filter capacitors, and dropping resistors. To get a replacement that will stand up in service, you must duplicate, or exceed, the ratings of the original. (You can always go up, but don't go below!) In tube power supplies, you'll have high voltages. So, you'll have to select rectifiers with an ample PIV (peak inverse voltage) rating. In a circuit with 500 volts dc output, you should use rectifiers with 1000 volts PIV. In transistor power supplies, with their low voltages, this isn't important. All rectifiers have PIV ratings far above what you'll need.

Current Ratings

More important, in both types, are current ratings for rectifiers. Check the maximum current drawn, and always use rectifiers with maximum ratings well above this. One good way of quick-checking this is to note the value of the *fuse*. For example, if the dc line has a 2.5 ampere fuse in it, the rectifier should be able to handle at least 5 amperes. The higher rated types will run cooler, and last much longer.

Small rectifiers do not need heat sinks. However, in some of the very large amplifiers, you will find rectifiers in the "stud-mounted" cases, using the chassis as a heat sink. Fig. 5-10 shows a couple of rectifier cases of this kind. The heavy threaded stud is bolted firmly to the chassis, or to an insulated heat sink if the circuit requires it. You can get these in two types, with either the anode or cathode connected to the stud.

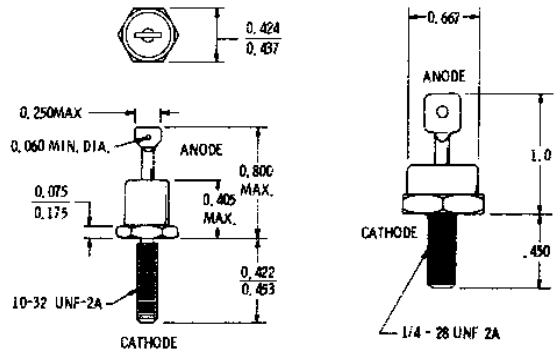


Fig. 5-10. Stud-mount rectifiers used in heavy duty amplifiers.

Filter Capacitors

Bad filter capacitors will make up a lot of your work in these power supplies. When choosing a replacement, you don't have to have an *exact* duplicate, The only thing you need is one at least as big as the original, and with equal or higher working-voltage rating. You can always use a *larger* filter capacitor, but never use a smaller one. If the actual voltage applied to the capacitor is say 50 volts, use at least a 100-working-volt type, and so on. Here, too, the safety factor is important.

In tube amplifiers, a lot of the filter capacitors will be multiple section can types. Transistor amplifiers tend to use more single-unit types. In the multiple-element filters, if one unit goes bad, always replace the entire unit. Do *not* disconnect the bad one and tack a single-unit capacitor across it. (And of course, do

not commit the cardinal sin in making capacitor replacements—tacking a new unit across an open section without cutting the old one loose. This is *definitely* out. The old capacitor may short, leak, or develop leakage to the other sections.) Whatever fault conditions developed inside the can of the original will in time affect all of the remaining good sections. So, get it out of there.

Chapter 6

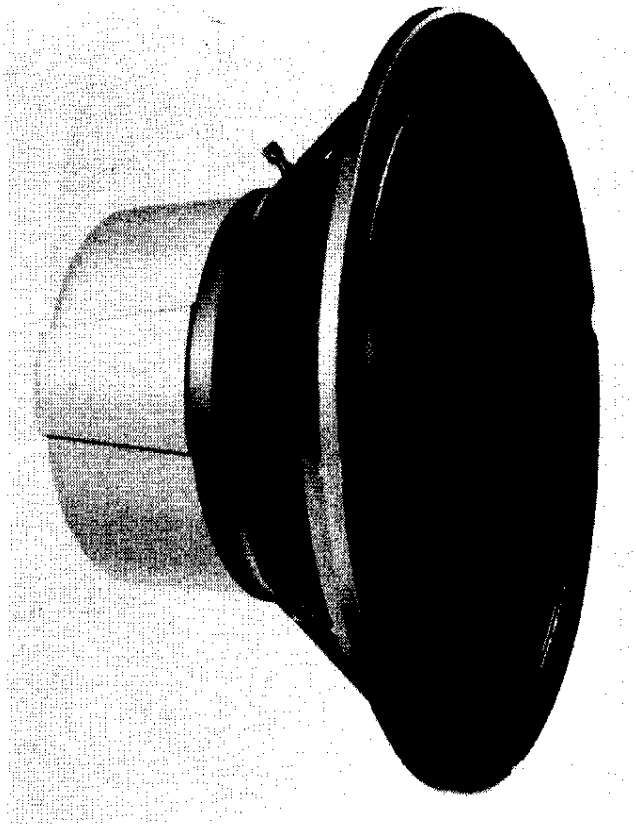
Output Stage — Transformers and Speakers

The output stage of all amplifiers is very important in more ways than one. It uses practically all of the *power* taken by the amplifier, it determines the power *output* level, and it can cause a great deal of the distortion. Parts in this stage work as hard as the parts in the power supply. So, they have a greater failure rate than others, and require more care in selecting suitable replacements. This is most especially true in transistor amplifiers and in the higher-powered tube types.

Tube and transistor output stages have slightly different characteristics, and even the output transformerless transistor output stages differ between the two basic types, the stacked and complementary-symmetry. So, you must know these characteristics for they affect the type of tests you use on them. Also, they differ in one very important respect; with tube-types, using output transformers, the speaker must NEVER be left off (open) when the amplifier is turned on. This will damage the output transformer. In transistor transformer-output types, the same applies. However, OTL transistor amplifiers can be turned on with the speaker open, with no damage; however, these circuits will not withstand even a momentary SHORT-CIRCUIT across the speaker terminals! So, while making tests, be absolutely sure that your wiring, extension leads, etc., are kept well clear so that there will be no chance of a short between the speaker leads. This can blow not only one but several large and expensive output transistors in a fraction of a second.

SPEAKERS

Speakers, too, have changed drastically in the last few years. Not too long ago, about 15 watts rating was the best you could get in a cone-type speaker, even in the very best "pa type" units. With the development of the super power amplifiers of today, something had to be done. So, loudspeaker makers labored mightily, and came up with super-speakers to match the amplifiers. It is possible to get single cone-type



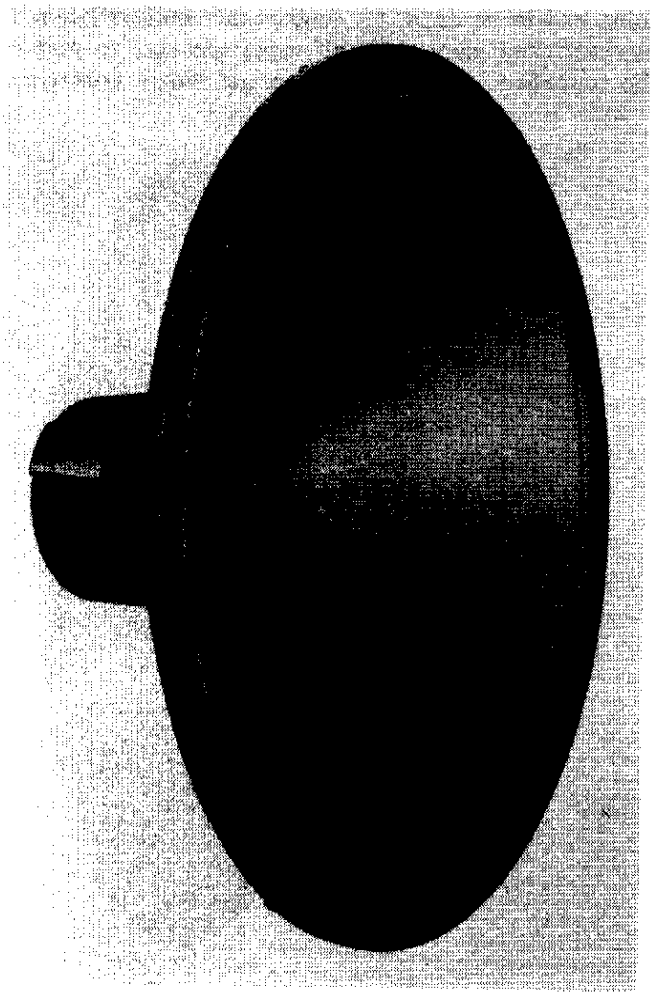
Courtesy Electro-Voice Inc.

Fig. 6-1. Speaker with peak-power rating of 300 watts.

speakers now that will actually carry *150 watts* of pulsed (program) power, in a single unit. Fig. 6-1 shows one of these speakers. The *peak* power rating of this speaker is an amazing 300 watts.

The "bass-amp" speakers have the hardest work, since in all musical tones, the largest percentage of the audio power is in the lower frequencies. (It takes more power to cause the speaker cone to move over the greater excursions at slower speeds.) Here, too, the super-speakers are used. A 15-inch speaker used to be considered a big one. They are now making them up to 30 inches in diameter, as you can see in Fig. 6-2. This unit has a 100-watt rating, 200 watts peak.

When replacing speakers like this, you must be sure that the replacement speaker will handle the full power output of the amplifier. This is not too important in the smaller amplifiers, say up to 25-30 watts, but if you have one of the monsters, look out! If you replace a high-power speaker with a $29.95 "super-bargain" import type, and turn the thing on to full output, you'll blow the cone all the way across the room. (This has actually happened; one musician blew *four* new speakers at the same time, so they weren't as much of a bargain as he had thought.)



Courtesy Electro-Voice Inc.

Fig. 6-2. Speaker that is 30 inches in diameter.

OUTPUT STAGE TESTING

If you are to service an amplifier which makes no sound at all when it's turned on, trouble in one of two places, the power supply or the output stage, is indicated. As usual, the power supply should be checked out first, since no amplifier can work unless it has the right power supply.

The first thing to check is the ac supply. This is reasonably simple; just look at the pilot light. If this lights but you hear no sound at all, you know that the amplifier is getting ac power; the line cord and plug at least are still all right. Next, check the fuses or circuit breaker. If the fuse is blown DO NOT replace it with a bigger one "for testing," especially in transistor amplifiers. You may cause more damage.

There are several ways of checking an amplifier like this with safety. One is to replace the fuse with one of the same size. Turn it on. If this pops right away, you know that there is still a short circuit. Another way is to clip a circuit breaker, of the same rating as the fuse, across the fuse terminals. If this pops out, it can be reset. (The drawback to this is that it requires quite a few different circuit-breakers on hand.)

The best way of doing this is to use the wattmeter and a variable transformer. Hook them up as shown in Fig. 6-3. The variable transformer is plugged into the wattmeter, and the amplifier line cord into the variable transformer. Replace the fuse. Now, you're ready. Turn the output of the variable transformer all the way to zero, and turn the amplifier power switch on. Note the normal input wattage on the rating-plate of the amplifier, which should be on the back apron of the amplifier chassis. Now, we're ready.

The variable transformer dial will be calibrated to show the output voltage. Turn it up slowly, watching the wattmeter. For example, this amplifier has a normal drain of 200 watts, at 120 volts ac input. As you turn the dial up, the wattmeter will begin to show

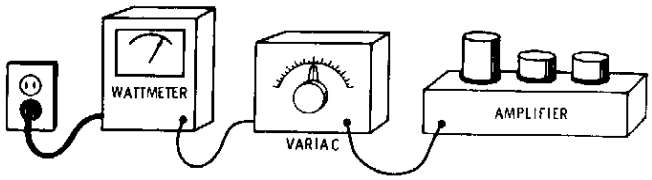


Fig. 6-3. Using a variable transformer and wattmeter to verify a short-circuit in an amplifier.

a reading. If you get up to about 35-40 volts input, and the wattmeter already shows 200 watts, stop! This tells you that there very definitely is a short-circuit inside the amplifier.

Now, we know that we have a short, and the chances are that it's in one of two places—the power supply or the output stage (the two "heavy-current" stages). So, we have to clear one or the other. The power supply is easiest. Just unhook the main supply lead to the output stage. This will be easy to identify, in most amplifiers. It'll go to the center-tap of the output transformer, in tube amps, and to the collector of the top transistor in the output pair, in solid state. This takes that stage out of the picture, leaving only the power supply.

Now, repeat the test. If the dc power supply will come up to the full ac line voltage, and shows only a comparatively small wattage drain (something like 30 to 40 watts is about right for an unloaded dc power supply), and the dc output voltages are normal or slightly high, we have cleared the power supply from suspicion. This leaves us with only the output stage. Of course, if the short turns out to be in the power supply, which it very often does, we find the shorted capacitor, rectifier, etc., or whatever it is, fix this, and then repeat the test. For a final test, reconnect the output stage power lead, and repeat the slow-voltage run-up test, to see if you can get it up to the full ac input voltage without drawing too much power. If the amplifier works, fine; the job is done.

CHECKING TUBE OUTPUT STAGES

If the short is definitely in the output stage, turn the power on at a low level, just enough to get a small amount of wattage. For tube output stages, check the dc voltages on plates, screen grids, cathodes, and grids of the output tubes. Note the dc voltage you're getting from the power supply. This should be a percentage of the normal voltage, say 15 to 20%. This will give you enough voltage to make tests, but not enough to overload anything.

A quick check of dc voltages will probably show you some point which should have dc voltage, but has none. For example, if you get zero on the screen grids of the output tubes (a point which will normally be at full B+, several hundred volts) turn it off, and take a resistance reading to ground. If you find a short, the screen grid bypass capacitor could be shorted. Disconnect it and check.

Zero voltage at the center-tap of the output transformer primary means a short there; most likely, a shorted decoupling capacitor, which is normally a big electrolytic. Possible, but rare, is a shorted output transformer. Disconnecting possible suspects one at a time, and checking with an ohmmeter, will quickly show you where the short-circuit is.

If you find no "dead shorts" in a tube output stage, that is, in the dc voltage supply lines and all parts connected to them, and the amplifier draws a very heavy current, but only after the tubes warm up, look out for a *bias* problem. (This is the one that makes the plates of the big output tubes get red hot!) In high-powered tube amplifiers, you'll probably find a special negative-bias voltage circuit, to supply the high bias voltage needed to make the output tubes work in Class-B. Fig. 6-4 shows the basic circuit of this.

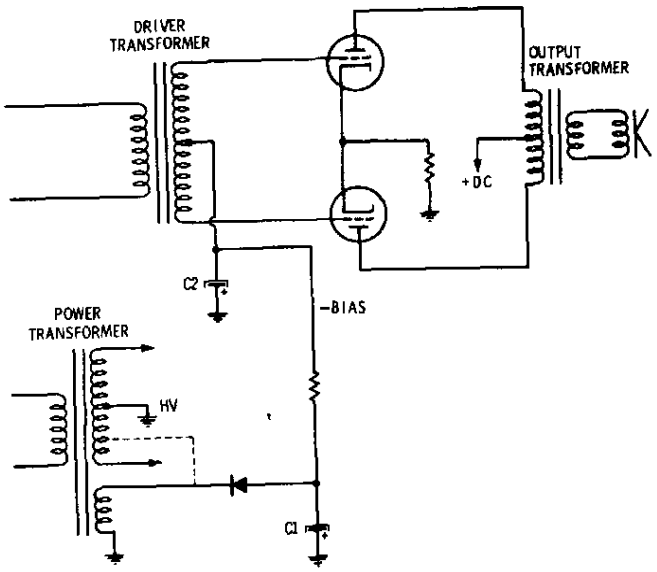


Fig. 6-4. Negative-bias voltage circuit.

This bias supply will run somewhere around 45 to 50 volts as an average. It is developed by a diode rectifier, on a special winding on the power transformer. It's filtered by a capacitor, and decoupled by an RC network. If the decoupling capacitor C2 should be shorted, the tubes will have zero bias, and draw a very heavy plate current. Quick-check for this—pull both output tubes, turn the power on, and take a dc voltage reading right on the grid terminals of each socket. This should show the negative bias voltage, slightly higher than normal reading, due to the loss of load. Actually, there is only a very minute current in *this* circuit, but the dc voltage will rise due to the loss of load current on the power transformer, from the normal heavy output-stage current. Any trouble in this is easy to fix; it will probably be a shorted capacitor, shorted or open rectifier, or open decoupling resistor, (or that classic problem "just a loose wire"). In one case of an intermittent overheating of

output tubes, the plastic covered wire from the bias supply was found to be shorting to the sharp corner of a terminal strip.

Fig. 6-4 shows the output tubes, with a driver transformer to supply the grid-drive signal. In quite a few circuits, you will find the output tubes driven from a phase-inverter stage, with coupling capacitors to transfer the ac signal. The "other end" of these capacitors is always connected to a source of positive voltage—the plate/cathode of a split-load phase inverter, etc. So, if there is even a small dc leakage through the capacitor, this will cancel out the negative bias on the output tubes, and away we go again.

Severe leakages or shorts cause the output tubes to get red hot from loss of bias. Small leakages upset the bias, not enough to cause the output tubes to overheat, but this will cause a very severe distortion. This makes the sound very "fuzzy," due to clipping, or oversaturation of the output tubes.

Quick-check for this condition, in any amplifier, external-biased or self-biased—pull both output tubes, turn the power on, and read the dc voltage on the grid terminals of the sockets with a vtvm. In self-bias circuits, this should be absolutely zero, for there is no voltage applied. In external-bias circuits, read the dc voltage at the output of the bias supply, then at the grid terminal itself. There should be absolutely no loss or drop. For example, if you read −50 volts at the supply, and −40 volts at the grid, you're losing 10 volts somewhere. Disconnect the capacitor at the grid end, turn the power on, and take a dc voltage reading (vtvm *only*) on the open end of the capacitor. Needless to say, this had better be zero! If you get any "permanent" reading, aside from the initial charging kick, which should leak off in about 15 seconds, replace the capacitor.

Some of the external-bias circuits will have a "balance pot" connected in the bias circuit. This allows the adjustment of the cathode currents of each output tube, for best balance. A link will be provided in the cathode circuits, so that you can open this and hook in a dc milliammeter. You'll notice this feature in several of the larger tube amplifiers, in the schematic section of this book.

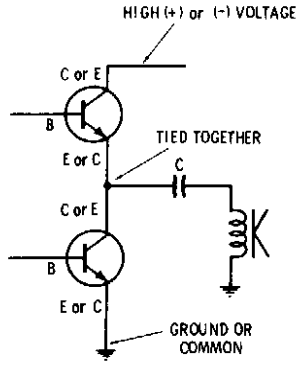
CHECKING TRANSISTOR OUTPUT STAGES

To make tests on transistor output stages, use the same power-supply test methods just given. Disconnect the output stage, and make sure that the dc power supply is in good shape. After this, use the same low-voltage setup to get some information as to what is actually going on. Due to the nature of transistor output stages, it is *very* difficult to find shorts in the dc power supply with an ohmmeter. If you happen to connect the ohmmeter so that it forward-biases one of the rectifier diodes, you'll see what looks like a "big, fat short", but is *not!* When taking any short-checks in transistor circuits, always take the reading, then reverse the ohmmeter prods to see if the low reading you get is due to a forward biased transistor or diode junction, or not. Of course, if you get a zero reading both ways, you can be reasonably sure that something is wrong. Disconnect loads to find out.

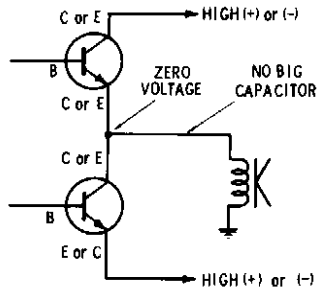
Voltage Identification of the Circuit

Fig. 6-5 shows the two typical circuits you'll find. The single-polarity type is shown in Fig. 6-5A. You will *always* find the big electrolytic coupling capacitor used. However, depending on the type of circuit the designer chose, you may find the collector and emitter connections changed up quite a bit. The base will always be the same, the input; but you may find the other two reversed. The dc supply may be fed to the collector or emitter of the top transistor, and either the collector or emitter of the bottom one may be ground. Voltages may be either positive or negative. So, on the first check, just look for the "high voltage," and pay no attention to its polarity. What you need to know is "Is it there or not?"

The dual-polarity type of circuit (Fig. 6-5B) can be identified by several things. For one thing, there will be *no* big coupling capacitor from the midpoint



(*A*) *Single polarity.*



(*B*) *Dual polarity.*

Fig. 6-5. Voltage identification of circuit used.

to the speaker. The speaker is connected from the midpoint to ground or common. So, this point will be at zero dc voltage. The "open ends" of the circuit, that is, the emitter/collector of the transistors, will be at the same *voltage*, but of opposite polarities.

I believe that you will find the majority of transistor amplifiers use the single-polarity circuit for the output stage, as shown in Fig. 6-6. If so, then you will have a very convenient test point—the "midpoint voltage" of the circuit. What you read here will tell you a great deal about the circuit condition.

As you can see, the two transistors are effectively connected in series across the dc power supply. The maximum dc is connected to the top transistor, and the lower one is grounded. (Note: You'll find these reversed, and of different types, in the complementary-symmetry circuit and so on, as you saw in the earlier discussion of these circuits, but the basic principle will still be the same. With a single-polarity power supply, the voltage will always divide up almost evenly.)

So, if the circuit is working properly, you'll find approximately half of the maximum dc supply voltage on the midpoint—the junction of the two transistors. If you find zero voltage at this point, check to see if the dc power supply is of the dual-polarity type. If so, you'll find a high negative voltage on one transistor, and a high positive voltage on the other (emitter or collector, depending on how they're connected). However, there is one firm clue you can use; if you see the collector (or emitter) of one of the power transistors connected directly to *ground* or common, then it's a single-polarity type of circuit.

If the midpoint voltage is zero, check the dc power supply on the top transistor. If this is the full dc supply voltage, the top transistor is open. Don't take this for granted, of course; take the transistor out of the circuit and check it. If you find the full supply voltage, or at least ⅔ of it, on the midpoint, the top transistor is shorted. (This will normally blow the fuse.) Shorted transistors can usually be checked in-circuit,

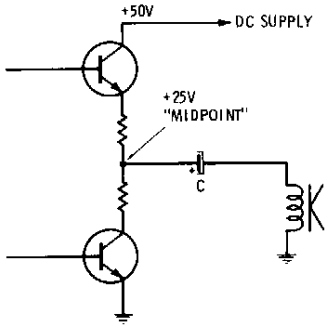


Fig. 6-6. The midpoint voltage on a transistor transformerless output circuit can provide a valuable clue.

by taking ohmmeter readings across the emitter-collector junction. If you get zero ohms with the prods both ways, the chances are it's shorted. Once more, do not take this as final; take the transistor out and repeat the ohmmeter test. If it checks shorted out-of-circuit, it is. Silicon transistors, when they short, normally go to a complete zero-ohms reading. Of course, if you check one out-of-circuit and get a completely open-circuit reaction, prods both ways, this junction is open. You should get the diode effect between any two terminals of the transistor: low resistance one way, high resistance with ohmmeter prods reversed.

With any of these troubles in the output stage, you will naturally hear no sound in the speaker. If the big coupling capacitor is open or if the speaker voice coil is open, your midpoint voltage will be away off. The actual voltage you find here will depend upon the rest of the circuitry (not shown here) but there will often be dc feedback networks which will give you enough continuity to show up some voltage at the midpoint. However, if the capacitor is open, the dc voltage on the lower transistor will certainly be abnormal, since it is from the charge-discharge action of this capacitor that it gets its power supply. The same thing will happen if the speaker is open; this is the "ground-return" for the capacitor, so it can't charge up to the normal voltage.

If the capacitor is leaky, the midpoint dc voltage will be pretty low, although some sound may go through. There will be a terrific distortion, however. This is due to the unbalance caused by the lower transistor not getting its fair share of the dc voltage. A leaky capacitor won't charge to the full voltage and hold it.

I have said and I say again: If you find one output transistor defective, in this type of stage, don't replace just one. Put in two new ones, and be sure that they are a matched pair of whatever type is needed.

DRIVER STAGE FAULTS

In circuits using direct-coupled driver stages, be sure to check the base bias on new output transistors. The collector current of the driver *is* the base-current of the output transistor. Fig. 6-7 shows the basic circuit used. (Bias diodes and coupling to the lower transistor have been left out for clarity.) As you can see, the signal coming in drives the driver into conduction; its collector current flows through the base-emitter junction of the top output transistor.

So, if this driver transistor develops leakage, or if new output transistors have been installed, the output bias must be checked. Read the resting current (the current drawn by the output stage collectors, with *no*

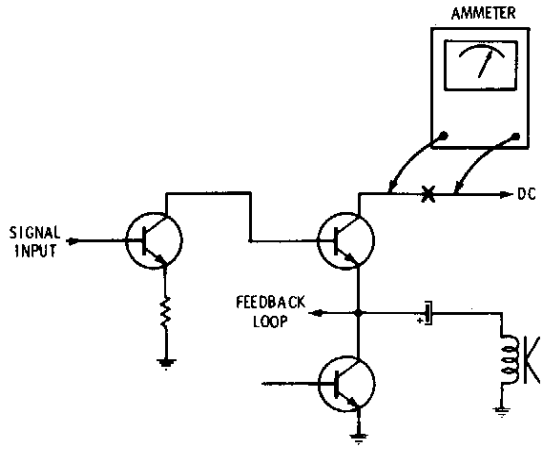


Fig. 6-7. Basic direct-coupled circuit.

input signal) of the output transistor; connect a dc ammeter into the collector supply circuit as shown. In a Class-B stage, there will be only a small fraction of the full output current flowing, with no applied signal. Some current is drawn to reduce crossover distortion.

If the rest bias is not correct, too much current will be drawn; the output transistors may get fairly warm. Normally, they'll stay quite cool, as long as there is no signal applied. If you find the transistor running warm, check the driver transistor and the dc base voltage of the top transistor. The chances are that you'll find this voltage a little too far in the "forward-bias" direction. A driver transistor, even though it checks good, can cause this if it has too high a beta. This factor is the *current gain* of the transistor; so, if it is too high, too much current will flow in the collector circuit, and over-bias the output. Try replacing it with one of about ⅔ the beta of the original. If this doesn't work, try one with a *higher* beta. Keep checking until the rest currents of the output transistors are back to normal.

You will sometimes find direct coupled preamplifier and driver stages with as many as three, four, or even five transistors all directly coupled. If so, you will have to take out at least two, in order to break the circuit to check the transistors. You cannot use an in-circuit type transistor tester in these; you have too many other things shunted across the transistor you're trying to check. The only definite test is to take it out and then check it.

CURRENT TESTING FOR FULL OUTPUT POWER

After the driver stage, bias, etc., has been checked out following transistor replacement, connect a dummy load resistor of the correct value to the

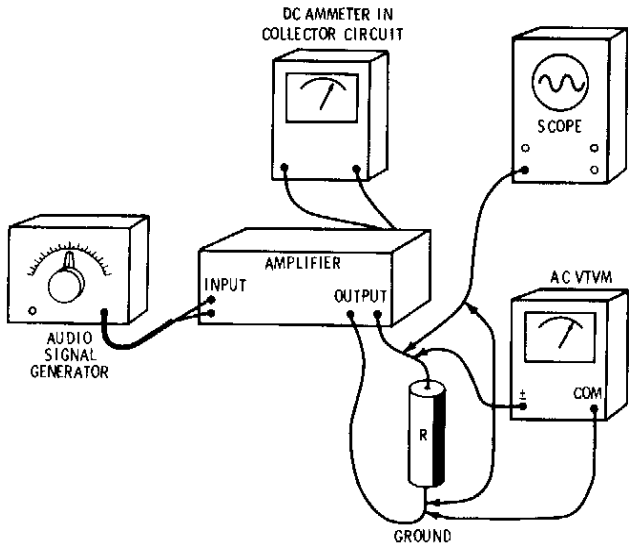


Fig. 6-8. Test setup for checking collector current, power output, and distortion.

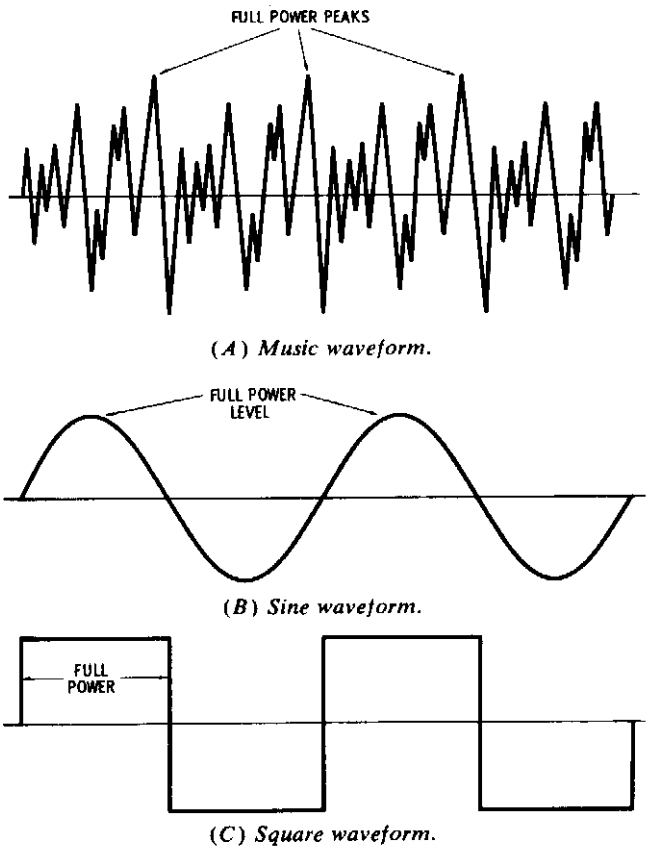
speaker terminals. In medium-powered amplifiers, this will probably be 8 or 16 ohms. In the super-power jobs, 4 ohms. If possible, check this figure on the schematic, or look for a rating plate on the amplifier. This information *should* be plainly marked at the speaker terminals of all amplifiers, however you won't find it on a great many. In any case, NEVER use a load resistor of less than 4 ohms.

Connect a dc ammeter in series with the output stage dc supply, as in Fig. 6-7. Connect the scope across the load resistor, and also an ac vtvm or vom. Connect an audio-frequency signal generator to the input, through a voltage divider, if necessary, to prevent too much signal voltage from being applied. Now you're ready to go. Fig. 6-8 shows the complete setup.

Start by turning the main volume or loudness control of the amplifier down. Set the input signal level at about 50 mV. Now, gradually bring the volume control up, watching the collector ammeter. As the output signal rises, you'll see the ac voltmeter start to read, and the waveform rise on the scope. The square of the actual rms signal voltage shown on the ac vtvm, divided by the value of the load resistor, equals the power-output being developed at any setting. This is from Ohm's law power formula $P = E^2/R$. Remember, for this test, do not bother to read the scope; it is showing peak-to-peak voltage, and right now we're reading rms on the meter.

Note the collector current reading on the dc ammeter. This should always be well *below* the maximum current rating of the new transistors. Checking fuses, or noting the maximum current rating on the schematic at the dc power supply, will give you an idea of what to expect. If everything seems to be work-

ing all right, let the amplifier run for about five minutes, at full power. Watch the collector current meter. This should *not* rise above the level you read for the full-power output. If you see this meter start to "creep up," look out! This could indicate an excessive rise in junction temperature, and, with germanium power transistors, the chance of thermal runaway. A small increase may be all right, if it stabilizes after about one minute, but a steady creep upward should be checked out. This can be due to dry-mounting of the new power transistors, or to a very slightly leaky driver transistor, etc. Do not run this for more than five minutes at high power.



(*A*) *Music waveform.*

(*B*) *Sine waveform.*

(*C*) *Square waveform.*

Fig. 6-9. Difference in power peaks among test signals.

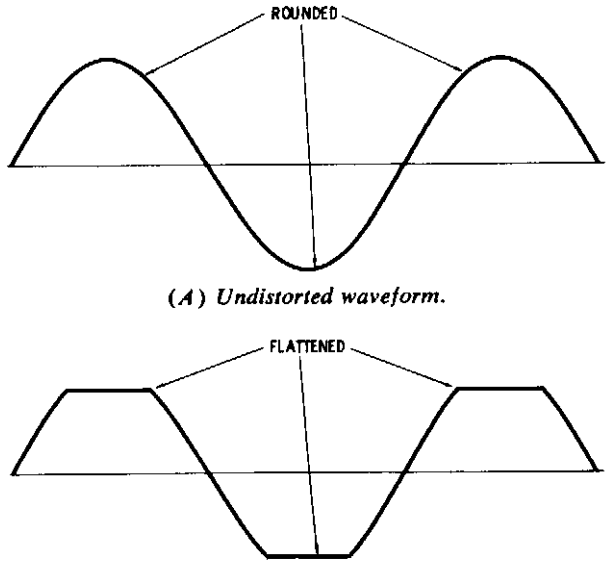
Also, if your audio signal-generator has a square wave output, do not use this for this type of testing. There's a reason; the guitar amplifier is intended to develop a high output power, but musical waveforms are not "square," they are usually sharply peaked. While it does develop high audio power, this type of waveform drives the amplifier to full output for only fractions of a second. Fig. 6-9 shows how and why.

In the music waveform of Fig. 6-9A, the full-power peaks are very sharp, lasting only for a millisecond or so. In the sine wave of Fig. 6-9B, the rounded peaks keep the amplifier driving for a little longer time, but not too much. However, the square wave of Fig. 6-9C turns the amplifier on, full-out, and *keeps it on* for a full half-cycle, switching then to the lower transistor and repeating. So, a test of this kind can damage a perfectly normal amplifier, because of the high power dissipation due to excessive "on-time."

TESTING FOR UNDISTORTED POWER OUTPUT

To find out exactly how much undistorted power output an amplifier is capable of delivering, we use the same setup as before. If the collector current stays within safe limits, you can remove the dc ammeter. Feed in an input signal, at any frequency below 2000 Hz. (Most of the standard tests are made at 1000 Hz.) Set the scope sweep to display about three cycles of this signal, across the load resistor. If the scope can be calibrated in peak-to-peak voltages, use this and divide by 2.8. If not, use the rms ac voltage reading on the vtvm.

Now, we're ready. Increase the amplifier gain, adjusting the scope to keep the signal on the face of the tube. Watch for the point where the tops of the sine waves just start to flatten out. At Fig. 6-10A, the normal signal shows rounded peaks; at Fig. 6-10B, the tops of the waveforms have just begun to show flattening. This is the point where the amplifier has just begun to "clip." This is distortion. Back the amplifier gain down until the waveforms are rounded again. Now, read the ac rms voltage and do the arithmetic. The result will be the maximum undistorted power output of this amplifier with this load. This level is sometimes found under the name "music power."



(*A*) *Undistorted waveform.*

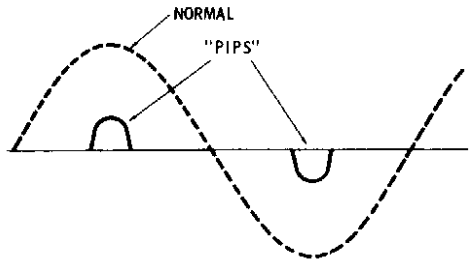
(*B*) *Clipped waveform.*

Fig. 6-10. Checking output waveform of amplifier.

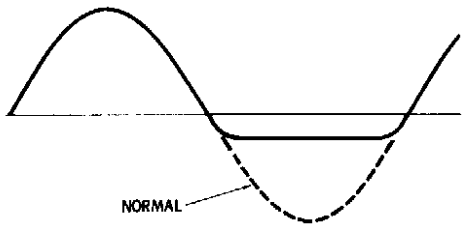
FINDING DISTORTION OR LOW POWER WITH SCOPE

The signal you see on the scope, across the load resistor, can be very useful. It will tell you if there *is* any distortion in the amplifier, and, with careful checking, tell you where. For example, if you see a waveform looking something like that in Fig. 6-11A, after replacing the output transistors, even with the amplifier gain turned up, this usually indicates a lack of sufficient drive signal to the bases of the output pair, or incorrect bias on the output pair. With this type of waveform, you'll usually have a terrible distortion, and the power level will be far below normal. Instead of driving the output pair into conduction over a full cycle, the drive signal is getting high enough to cause conduction only in the very middle of the cycle. The stage should be working in Class-B, but it is actually working in something that could only be called "Class-C."

An output signal with the lower half-cycle missing or far below the amplitude of the upper half, indicates a very severe unbalance in the output pair. This is shown in Fig. 6-11B and may not look exactly like this, but, if you can see a decided unbalance, find out why. This, too, is a cause of distortion. Check the speaker coupling capacitor, any bias diodes that may be used, and the driver stages.



(A) Caused by low drive or improper bias.



(B) Caused by half of the output stage not conducting.

Fig. 6-11. Distorted output waveforms.

A REALLY BIG MISMATCH

Fig. 6-12 shows the waveform of a really weird mismatch. This amplifier came in for service with the complaint that it "just doesn't sound right!" It didn't! Almost, but not quite. Voltages were checked, and found to be very near normal. But, when a distortion test was made with the scope, this is what I saw. Note the crossover. One-half of the signal is apparently all right, but the lower half is "taking off" a little late. Note that it goes *along* the baseline for quite a way before it begins to conduct.

This told me right away that it was a bias problem. A careful examination of the output stage showed that *one* of the output transistors had been replaced, leaving the other original in. Both were removed, and tested. Both were good. However, cross-checking against the replacement guide brought out an astonishing fact. One was a silicon, the other was a *germanium!* The circuit was a stacked transformerless output.

The characteristics of the two transistors were pretty close. However, you can see what happened. Silicon transistors need a 0.6 volt bias to start conducting; germanium, 0.2 volt. The silicon transistor was in the lower half. So, it didn't begin to conduct for quite a while, causing the output to go along the baseline until it reached the conduction level before it went into conduction.

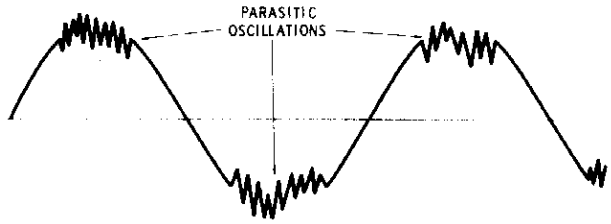
Incidentally, as an experiment, I tried two germanium transistors, then two silicon, in this unit. The results were mildly astonishing; both sounded pretty good. The originals were germanium. A bit of bias adjustment made the silicons work.

Fig. 6-12. Crossover distortion caused by unlike transistors in output pair.

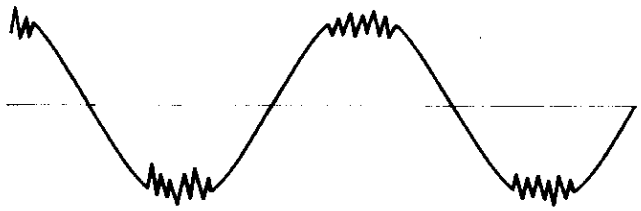
CHECKING FOR PARASITIC OSCILLATION WITH A SCOPE

Fig. 6-13 shows another fault that's hard to find without the scope. The small "bursts" of high-frequency signal on the low-frequency signal waveform are parasitic oscillations. These take place in some of the amplifier circuits, usually due to a bad electrolytic filter capacitor somewhere. This allows the power supply to develop a "nonzero impedance" to ground, and unwanted signals can build up on common voltage supply lines, etc.

To find out, scope the power supply lines with a good sized signal being fed through the amplifier. If



(A) Output waveform with parasitics.



(B) Ripple waveform of dc power-supply lines.

Fig. 6-13 Checking for parasitics.

you find anything at all on the dc voltage supply lines, such as the waveform of Fig. 5-11B, look out! This is WRONG! Connect the scope to the point where the ripple waveform is the largest, then start substituting filter capacitors until you get rid of it. NEVER bridge an electrolytic filter capacitor across a dc supply line in a transistor amplifier without turning the power OFF. The resulting surge can blow transistors. Since these amplifiers come back on instantly, this is no trouble. Just turn it off, clip the substitute capacitor across the circuit, and turn it back on.

REPLACING OUTPUT TRANSFORMERS IN TUBE AMPLIFIERS

In better tube amplifiers, you will notice that the output transformer is almost as big as the power transformer. This is absolutely necessary to get good quality. As has been said before, the output stage dissipates about 95% of the power used in the whole amplifier. To be able to handle this kind of power without distortion, a big transformer with lots of iron is needed. This eliminates the core saturation that is responsible for distortion.

When an output transformer is replaced, check the schematic and the parts list. The type of tubes used and their operating voltages determine the wattage rating of the output transformer. For example, two 6V6s, with 250 volts on both plate and screen, are rated at 10 watts output. Two 6L6s, with 360 volts on the plates and 270 volts on screens, have an output of up to 45 watts. Check the tube manual to see what power you need.

To find a suitable replacement output transformer, you must have other information besides the wattage rating. Its primary winding impedance must match the load resistance (sometimes called load impedance) of the output tubes used, and the secondary winding must match the voice-coil impedance of the speakers. The 6V6s mentioned have a plate-to-plate load impedance of 10,000 ohms. With these tubes and a 16-ohm speaker the rating would be "push-pull plates, 10,000 ohms, to 16-ohm voice coil, 10 watts." Replacement transformers are available from many different manufacturers, all of whom publish very detailed catalogues with lists of output transformers of all sizes, shapes, and variety of ratings. Standard pa-type output transformers can be used; the only difference between them and the regular guitar-amplifier output transformers is in the number of extra taps on the secondary winding. They have provision for hooking up 4-, 8-, and 16-ohm speakers, a 500-ohm output, and so on. Simply use the leads you need and leave the rest open.

INVERSE FEEDBACK

Most of the larger amplifiers use inverse feedback in order to reduce distortion and give a better tone. The feedback voltage is often taken from one side of the output-transformer secondary winding at a speaker connection. (Fig. 6-14 shows how this can be connected.) The voltage that is fed back must be of the right polarity; it should produce degeneration instead of regeneration. (Regeneration causes oscillation, and degeneration stops it.)

If you replace an output transformer and turn the amplifier on, only to get a deafening howl, turn it off and change the polarity of the feedback voltage—move the feedback connection to the other end of the voice-coil winding. This reverses the polarity; opposite ends of a transformer winding are 180° out of phase with each other. In Fig. 6-14 note that a ground

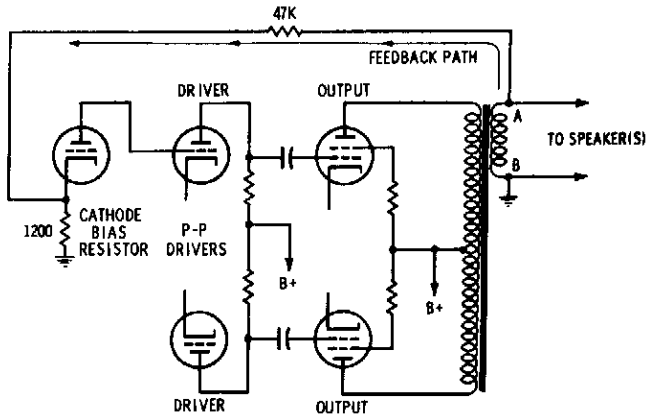


Fig. 6-14. Inverse-feedback connection on output-transformer secondary.

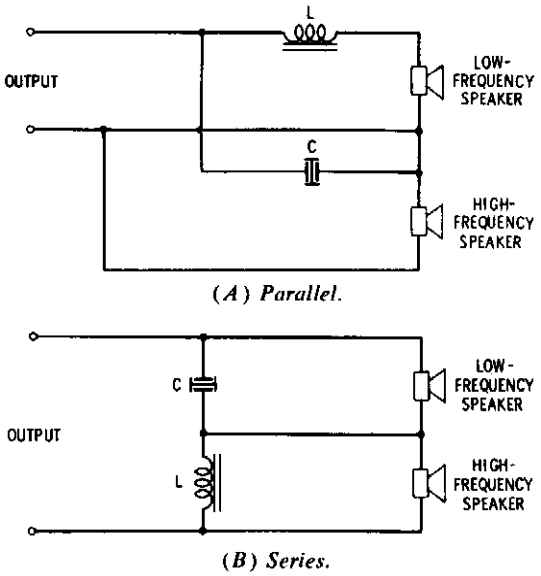
is shown on the end of the voice-coil winding marked "B." To reverse the feedback connection, move the ground to A and the feedback to B. The voice coil, being nonpolarized, can be left where it is. Do not move only the feedback lead; this grounds out all inverse feedback, and the tone will suffer. You might notice a little increase in volume with this arrangement; inverse feedback cuts the gain but helps the tone quality.

As a final precaution, never turn on an amplifier for testing without some kind of load hooked to the output-transformer secondary. If you do, the impedance in the power-output stage will be so far off that you may burn out the output transformer in just a few seconds. The stage is set up to work with an 8-ohm or a 16-ohm load across the secondary so that the primary winding will have the proper loading.

CROSSOVER NETWORKS WITH MULTIPLE SPEAKER SYSTEMS

Many of the better amplifiers will use "speaker systems" instead of a single or double speaker of the same size. Very large speakers (woofers) are most efficient in the low-frequency range. However, they're not too good for the very high frequencies. So, smaller speakers will be added; a medium-sized one, say 5 to 8 inches in diameter, for the "midrange," from about 2000 Hz up to 7000 Hz, and a very small speaker, sometimes a horn type, for the frequencies above this, up to a maximum of 20,000 Hz. This one, because it handles only very high frequencies, is sometimes called a "tweeter."

To get the best results with a multiple-speaker system, the various frequencies must be divided up among the different speakers. The lows go to the woofer, midrange to the medium-sized speaker (sometimes called a squawker) and the highs to the tweeter. Fig. 6-15 shows a simple circuit used to accomplish this frequency distribution. This is called a "crossover network." At a low frequency most of the sound energy goes to the woofer. When it reaches a certain frequency, it is transferred automatically to the tweeter; it is said to "cross over" from one to the other, hence the name. Only two speakers are



(*A*) *Parallel.*

(*B*) *Series.*

Fig. 6-15. Crossover networks.

shown; to use three, an additional part is added. Works just the same, though.

Here we take advantage of the basic characteristics of inductance and capacitance. A capacitor has a very high impedance at low frequencies that gets smaller as the frequency increases. The inductance has exactly the opposite effect—high impedance at high frequencies, very low at low frequencies. If components are hooked up as shown in Fig. 6-15A, the capacitor will let the lows go only to the woofer while feeding the highs through to the tweeter. In the series circuit (Fig. 6-15B) the high frequencies are bypassed around the woofer by the capacitor so that they appear across the inductance. Reverse the action for lows; the lows are bypassed across the tweeter by the inductance and blocked by the capacitor so that they have to go through the woofer.

TROUBLES IN SPEAKERS

All speakers are dynamic types. A voice coil, which is a hollow cylinder with a small coil wound on it, fits over a magnetic pole piece so the coil is suspended in a magnetic field (Fig. 6-16). The voice coil actually moves back and forth in a very narrow slot. If the cone warps or the voice coil touches the sides of the

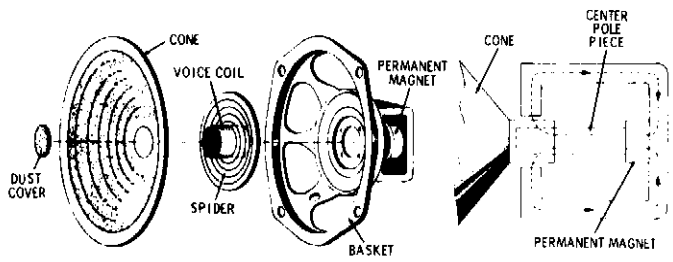


Fig. 6-16. Construction of a pm speaker.

slot at any point, a distorted, harsh, scraping sound comes from the speaker.

To test for this, place your fingertips on both sides of the cone at once, and push straight in and out. Listen to the sound: you shouldn't hear anything at all if the voice coil is floating freely. If it is dragging, you will hear a scraping sound. Trouble is usually caused by dampness that warps the cone or voice-coil form. There is no cure for this: modern speakers can not be realigned, as the old ones could. However, you can always have the speaker reconed at far less than the cost of a whole new one. This is especially true in the case of the heavy-duty speakers in high-powered amplifiers. Magnets never wear out, so if you replace the cone and voice-coil assembly, the speaker is as good as new. Usually radio parts houses do this kind of work.

Since speaker cones are basically paper, they deteriorate with age and then crack, especially under high volume. This can cause a crackling or buzzing sound on certain notes. If the crack is caught in time, it can be patched with cement. Don't use the so-called "speaker cement"—this dries out, turns hard, and usually breaks loose at one edge. After a while the speaker buzzes worse than it did before. The best cement the author has found for repairing speaker cones is rubber-to-metal cement. It stays flexible indefinitely and sticks very well. Never use scotch tape for patching cracks—it will dry up, come loose, and buzz horribly. If you must make emergency repairs to a speaker, use surgical adhesive tape; this has very sticky adhesive and is flexible.

FALSE SPEAKER TROUBLES

Now and then you will find an amplifier that will buzz when certain chords or notes are played on the guitar. This may sound like speaker trouble, and in some cases it is, but not always. The most common cause of this kind of trouble is something loose in the cabinet; this hits a harmonic resonance on certain frequencies, and buzzes.

The fastest way to find the trouble is to feed an audio signal generator into the amplifier and run the whole range of audio frequencies from 20 Hz up to 20,000 Hz. Somewhere in there you will hear the buzz loudly and clearly. If an audio signal generator isn't available, get out the record player and put on an audio test record with the same range of frequencies; there are several of these available. They do an excellent job in finding this kind of trouble. Loose bolts on the speakers or on the amplifier itself are common causes of buzzes; loose cabinet hardware—latches, clamps, etc.—may cause it, too.

CURING SPEAKER AND BAFFLE RATTLING

When you do find a rattle or buzz in a speaker baffle or cabinet, it can be cured without too much trouble. These rattles are due to something that is *loose*—a cracked piece of plywood, a brace, door, mount, or even the speaker frame itself, that isn't tightly mounted. Locate the cause of the rattle then bolt it down very tightly. Tighten all bolts and screws on the speakers themselves. If this is caused by a loose brace, shelf or mounting bracket, take the screws out and see if the whole piece is loose.

If it is, coat both the underside of the bracket and the mounting on the cabinet with a good grade of wood glue, then screw the bracket back down very tightly. If there weren't enough screws in it originally to hold it very firmly, drill small holes and add a few.

If the speaker cabinet is made of plywood that's just a little bit too thin, you may get "cabinet resonances" or funny sounds actually due to the sides of the cabinet acting as "cones" moving in and out with the sound. This shows up most often in the bass-amplifier speaker cabinets, which use tremendous amounts of audio power.

The cure for this is to "beef them up" by gluing pieces of heavy plywood inside the cabinet to make the walls thicker. These cabinets should be made of plywood no thinner than ½ inch, and ¾ inch is better. In some cases, you can cover the inside with the goop sold for damping metal-resonance in automobile bodies. Butter this on the walls, pretty thickly.

Chapter 7

Cables and Pickups

Not all servicing problems involve the amplifier chassis; there are occasions when parts mounted on the guitar need repair. Disassembly is usually fairly obvious; once the plastic or chromed cover plates are removed, all the electronic parts are exposed (Fig. 7-1). Be very careful in handling the guitar. Keep the finish protected as you would the most expensive TV cabinets. You might try leaving the guitar in the case while you work on it. A carpet sample from the furniture store makes a dandy bench cover to protect the finish of the guitar while it's being serviced.

MICROPHONE AND INSTRUMENT CABLES

One important feature of electric guitar systems is the use of shielded cable for all connections between the guitar, microphone, remote (foot) volume controls, and the amplifier. This is absolutely necessary in order to keep these sensitive circuits from picking up hum and noise. You need to know how the cables are made and to find ways of repairing them if they give trouble.

Because they are flexible and because they get hard wear from being rolled up, stepped on, pulled, and jerked, cables often break. If the hot wire (center conductor) breaks, the instrument will simply go dead. If the ground (shield) is pulled loose, the amplifier will give a very loud hum when this cable is plugged in: that is the key clue to cable trouble. When hum troubles are being checked out, the first thing to do is pull all cables out of the input jacks to find out whether the hum is in the amplifier itself or from an ungrounded cable.

Most guitar amplifiers use standard phone plugs (Fig. 7-2 shows the construction of one). The sleeve of these plugs is always connected to ground and the tip to the hot wire (center conductor). This provides an easy way to check for a broken cable: plug it into an amplifier input, turn the volume up on that channel, and touch the tip of the plug that goes into the guitar. If you hear a loud buzz, the cable is all right. If you get a loud hum, particularly if the hum gets louder when you hold the cable in your hand, the ground connection is open, probably at the amplifier end.

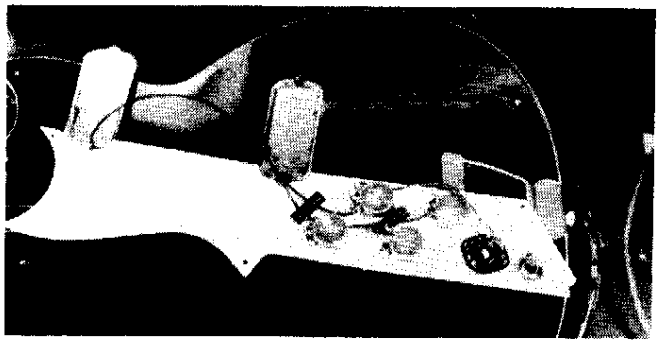


Fig. 7-1. View of a disassembled electric guitar.

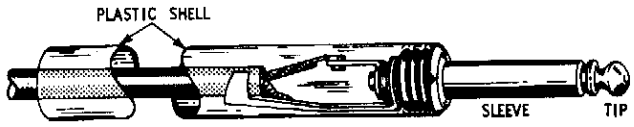


Fig. 7-2. Shielded cable attached to a standard phone plug.

If the cable ground is open at the guitar end, the amplifier will not hum too badly when you check the cable since only a half inch or so of the hot wire is exposed. However, when it is plugged into the guitar, the whole guitar will be hot: you will get a loud hum when you touch any of the metal parts. Take the cable out at both ends, and reverse it. Now, if the amplifier hums very loudly when you grab the cable, you have found the trouble. Hint: Because of the flexing of the cables, you will find almost all cable troubles located in the six inches at either end. This is where it takes the sharpest bending in use.

Installing Phone Plugs

There is a right way and a wrong way to install a phone plug. Here is the right way. Prepare the wire by cutting off the insulation for about an inch and a half; ring the jacket with a very sharp knife, being careful not to cut through the braided shield. Now pull out a pigtail from the shield (Fig. 7-3A). The easiest way is to double the cable very sharply just at the end of the jacket, then work a pointed tool such as a soldering aid through the braid, parting the strands but not breaking any more than you can help (Fig. 7-3B). Work the inner insulator and wire out through this hole. Pull the braided shield left empty out into a pigtail. This will not unravel, and it will give you a sturdy ground connection (Fig. 7-3C).

Trim the insulation off the hot wire *very* carefully so as not to cut the very fine inner conductor. In most cables you will find a silk inner wrapping which is hard to get off. The easiest way is to burn it off with a match or cigarette lighter (Fig. 7-3D). Then scrape the inner conductor very delicately, twist the strands together, and tin them with a clean soldering iron (Fig. 7-3E).

Next, put the shell of the plug on over the cable. Be sure that it is right end too. It's embarrassing to have to take the plug off just to reverse the shell—it's even more embarrassing to forget it completely, so watch it.

Solder the hot wire to the terminal going to the tip of the plug. You can tell which one this is; it will always be obviously insulated from the body of the plug. Also, it will be in the center. Next, fasten the ground pigtail to the sleeve terminal (Fig. 7-3F).

For long life the most important point in wiring a connector is to be sure that the strong ground pigtail is pulled tightly enough so that the hot wire shows just a little bit of bend. This means that any pull or strain on the plug and the solder joints will be taken up by the stout ground connection and not by the delicate hot wire. Some plugs are provided with a strain-relief clamp. This is fastened to the outer jacket of the cable. In some versions the jacket slips through a sleeve at the back of the plug and is held in place by being wrapped with strong linen thread. Other plugs can be wrapped with this thread if you want to make a good strong connection (Fig. 7-3G).

Splicing Coaxial Cables

There is a right and wrong way to splice broken cables, too. Splicing must be done correctly every time if the cable is to work properly. The splice must be as strong as the original cable, neat, and inconspicuous.

To start, cut back the outer jacket of each piece about 2 inches. Next, push the braided shield back over the jacket. Cut the insulation off the hot wire with a sharp knife, leaving about ½ inch insulated. (Save one of the pieces of insulation; you will see why in a minute.) Slit it and peel it off; that is the easiest way.

Burn the inner silk insulation off as before, and scrape the wires clean. Tin the hot wires, keeping the strands neat. Hold the center conductors of each cable parallel to each other, and solder them together very carefully. Don't leave a big blob of solder on the joint —it isn't necessary. If the wires are properly tinned, just touching them with the soldering iron will do the job. This soldering sometimes takes three or four hands or requires the use of some kind of clamp to hold things in place.

Take one of the bits of insulation you saved, slit it down one side, trim it to the right length, and slip it over the wire between the ends of the inner insulation. Press it tightly in place. If it is plastic, you can sometimes seal it very nicely by touching it lightly with the tip of the soldering iron. Make it smooth.

Take about a 5-inch piece of plastic electrician's tape, and slit it down the middle. If you have some of the special ¼-inch tape, use it without splitting. Hold one piece of the tape over a hot soldering iron until it gets limp. Then, start well up on the insulation at one end, and wrap the joint very smoothly. Keep your fingers off the sticky side as much as possible. Holding the whole thing over the soldering iron while doing the wrapping will help keep the tape soft and smooth. Make this neat; you will see why soon.

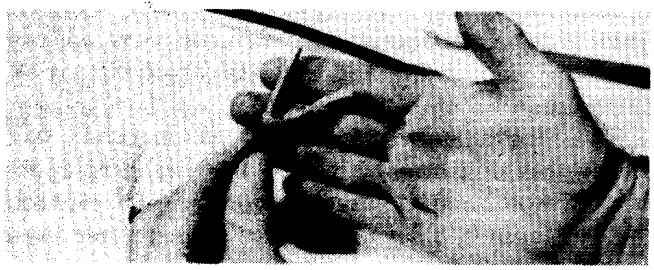
Take the other piece of tape and wrap it in the other direction, using the same method. Now, pull

one of the shields back down over the joint, smoothing it out as much as possible. Pull the other shield back over this one, smoothing it down too. Roll this between your fingertips to get things smooth and round. Now, clamp the cable down again, and tack the braided shields together, using a very clean soldering-iron tip and a low-melting solder. Be very careful not to hold the iron on the cable at one point for too long. If you do, you will melt the plastic tape or the inner insulation, and possibly make a short in the cable. Just "hit and git" until you get the shield tacked down in at least three places. Don't leave blobs of solder.

For the finishing touch, warm up a longer piece of tape and, starting about an inch back on the jacket, lay on two layers of tape in opposite directions. Keep your fingers off the sticky side until the tape is stuck down tightly—grease from your fingertips will make the tape pull loose. The best way is to hold it by one end, pull it tight, and then, with a sharp knife, trim off the piece where you have been holding it. You can get a very neat joint here by warming the tape and pulling it smooth. Properly done, the joint should be almost undetectable even when viewed from short distances.

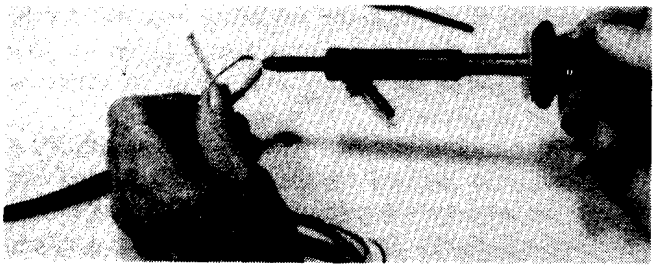
(*A*) *Step 1.*

(*B*) *Step 2.*



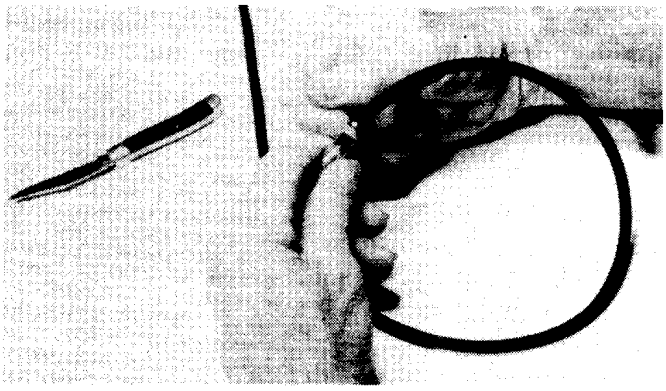
(*C*) *Step 3.*

(*D*) *Step 4.*



(*E*) *Step 5.*

(*F*) *Step 6.*



(*G*) *Step 7.*

Fig. 7-3. Attaching shielded cable to a phone plug.

MAGNETIC PICKUPS

If the amplifier itself is all right and the cables check out, then there must be trouble in the magnetic pickup on the guitar. Basically this is nothing but a roll of fine wire in a case, so it can be checked for continuity with an ohmmeter. Pickups have resistances ranging from 500 to 600 ohms up to several thousand ohms, depending on the amount of wire used and its size. The smaller the wire is, the higher is the resistance.

Fig. 7-4 shows the basic circuit of all pickups. The first check should be for continuity at the jack on the guitar. This can be made more easily by plugging one of the cables into the jack and checking between tip and sleeve of the open plug. The volume control is connected directly across the pickup coil in most units, so you will read a combination of both their resistances. If the volume control happens to be set at off, then you will get a fairly low reading. Turn it to loud or full on.

Volume controls are usually a half-megohm or larger—quite a bit larger than the resistance of the pickup coil. If you read the full resistance of the volume control, then the pickup coil must be open. Otherwise you get the resistance of the coil in shunt with the control, and your greatest resistance would be about 10,000 ohms.

If there is no variation in the resistance when the control knob is turned, then the control is open. Replace it. If the pickup coil is open, this is a different story indeed. Many of the pickup units are sealed in metal cases and are not designed to be opened for servicing. However, if it is definitely open, you can't hurt anything by trying, and you may be lucky.

First, get into the case—this may not be so easy. Many have metal lids on the bottom, soldered in place. Pry or melt the solder loose, and take the lid off very carefully to expose the coil. Watch out that you don't pull the wires loose in taking the lid off if they happen to be stuck to it by varnish or insulating material.

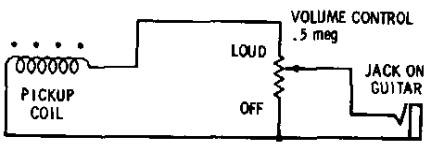


Fig. 7-4. Schematic of pickup coil and its volume control.

You will be able to see where the wires come into the case from a shielded cable and join the coil; the shield will always be soldered to the case just inside the point of entry. Get a jeweler's loupe or a powerful magnifying glass, and check the very fine wires. In many cases the wires have been found to be broken just inside the case. If so, they can usually be picked up out of the winding, cleaned, and soldered back.

Pickups are always wound with very fine enamelled wire. Use a delicate touch in working with it; a sharp-pointed tool is handy. Find a small round wooden stick, and drive a sharp pin or needle into one end; this makes a good pick for working wires loose.

If you can find the two ends of the wires, check them for continuity; you can touch the broken end of a wire with the tip of a clean ohmmeter prod while holding the other prod on the case. Find out if the coil has continuity from this point to ground.

To make a solder joint with such fine wire, don't try to clean it—it will break. If there is enough of an end available, heat it with a cigarette lighter; this burns the enamel off and lets you get to the copper. You can sometimes dissolve the enamel off by very carefully applying a little acetone to the end of the wire, but don't let it drip into the coil itself. Lay the coil on one side if this is attempted.

If you can't clean the wires at all, hold them close together and start heating the ends with a soldering iron. This will require a very clean iron with a very fine, sharp tip. Touch the wires with the end of a piece of solder, using some of the low-melting-point fluxcore solder now available. The soldering flux and heat will eventually burn off the enamel and make the joint. Just a "wee touch" is enough. You won't have enough to twist; be satisfied with any kind of a lap joint. Recheck continuity. If this does the job, tuck the joint very carefully back inside the case, and paint it with some kind of insulating dope. Let this dry, put a very small piece of plastic tape over it (to keep it from shorting to the lower lid), and replace the lid. This will not have to be resoldered completely, just enough to keep it in place.

Chapter 8

Customer Complaints

If a guitar amplifier is dead, the problem is relatively simple. Find the bad component and replace it. Procedures mentioned previously can be used so that the troubleshooting can be done in a logical manner, using a minimum of time. Probably more difficult to service are the cases where the amplifier is working, but not in a satisfactory fashion. There is a strong tendency here to proceed in a hit-or-miss fashion, substituting a tube here or a component there, in the hopes of finding a cure. Don't do it; the whole secret to speedy servicing is an orderly search for defective parts.

Often the owner gives valuable clues to the nature of the problem when he describes what is wrong. Listen carefully to him, and, if possible, verify what he says by listening to the amplifier while he is present. The player's ears are sensitive to the sound of an instrument in a way the serviceman can never be; even so, you can't do much to repair an instrument if you can't hear what is wrong.

Some of the common customer complaints are listed in the following sections along with suggestions for finding the source of the trouble.

DISTORTION

One of the worst problems in all audio amplifiers is distortion. This simply means that the amplifier isn't putting out what goes into it. An amplifier must never *change* the shape of the signal fed into it—it must only make the signal bigger. If the amplifier changes the waveshape of the note, there is distortion. If an amplifier tube operates on any but the linear part of its curve, troubles develop. Fig. 8-1 shows how this works; if the stage is properly biased, the output signal is exactly the same shape as the input. If bias is wrong, then the signal is changed—clipped or otherwise distorted. It is possible even to get a frequency-selective form of distortion; some notes are amplified clearly, others are distorted. (This is a simplification of what actually happens, but it's good enough to illustrate the problem; it can be fixed.)

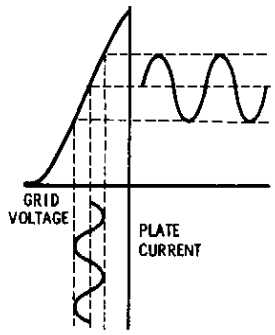
You must work on the assumption that the guitar and amplifier were practically distortion-free when new, and try to make them work as well as they did then. This means finding all of the parts that have drifted off tolerance and replacing them, replacing all tubes that have weakened or developed grid emission, replacing all leaky capacitors, and so on. If you take a stage at a time, you can gradually get the amplifier back to normal.

Probably the most frequent cause of distortion is leaky coupling capacitors between stages. This has been covered previously, but don't overlook it.

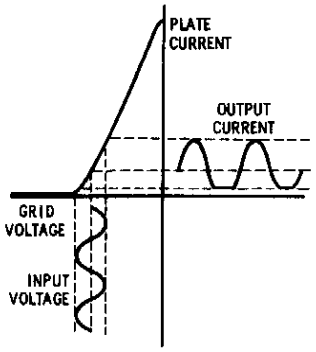
Using an Oscilloscope to Find Distortion

About the only instrument that makes it easy to find distortion is the oscilloscope since the ear is pretty unreliable for obvious reasons. However, if a pure signal is fed to the input of a stage and something else comes out, then there is distortion in that stage. Fig. 8-2 shows how this works.

Here, a pure signal (W1) is fed to the input, and the same signal is undistorted at the output of the next two stages (W2 and W3). However, look at the output of stage 3 (W4). Something has happened here. This pinpoints the source of the distortion; something is very definitely wrong in the third stage.



(*A*) *Output not distorted.*



(*B*) *Output distorted.*

Fig. 8-1. Transfer curves showing signal amplification.

To find the cause of the trouble, start checking parts. First, replace the tube, because it is the easiest. Then, check the operating voltages, paying particular attention to the grid bias voltage. Most RC-coupled stages are very simple; there is actually nothing to them but three resistors, two capacitors, and the tube. If there is distortion in a stage, one of these parts must be bad.

Transistor amplifiers are checked in exactly the same way. Feed in a known good signal to the input, check its waveform *before* it starts through the amplifier, then simply follow it through the whole signal path. At the point where it is being distorted, you'll see it. Clipping is probably the most common cause of distortion in solid-state amplifiers.

Clipping is due to incorrect bias; this in turn can be caused by a bad bias resistor, a leaky electrolytic coupling capacitor, or, and possibly the most frequent cause, a transistor which has developed too much leakage. This is something that *cannot* be checked in-circuit, because of the components which are connected across the transistor. Take it out, and check it with a good transistor tester.

In older amplifiers, germanium small-signal transistors were used. These have some leakage; not a lot, just a few microamperes. This is normal (if you have doubts, try a new transistor in there). However, most of the transistors found in later amplifiers will be silicon types, and the normal leakage for these is zero.

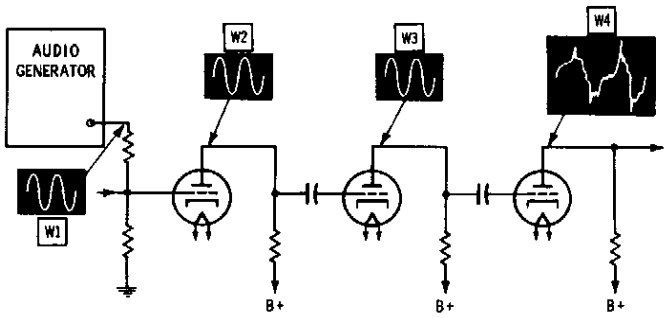


Fig. 8-2. Waveforms at critical points in an amplifier.

None at all. So, if you find a silicon transistor showing as little as 10 *microamperes* of leakage, replace it. It's bad. This is particularly critical in power transistors, but can cause trouble in preamplifiers and drivers as well.

As an example of how the scope can help, I once found an amplifier where the complaint was simply "It sounds like . . . !" Feeding in sine-wave signals didn't seem to show anything at all. However, when the guitar was hooked up to the amplifier and a few chords were played at high volume, the trouble was apparent. On the oscilloscope there was a pattern that looked like Fig. 8-3. (Because of the movement in this pattern, it couldn't be photographed, but this is an accurate reproduction.)

Several different frequencies were present at the same time: this caused a rapid movement of the scope pattern. However, by careful observation and juggling of the sweep controls, I finally spotted the

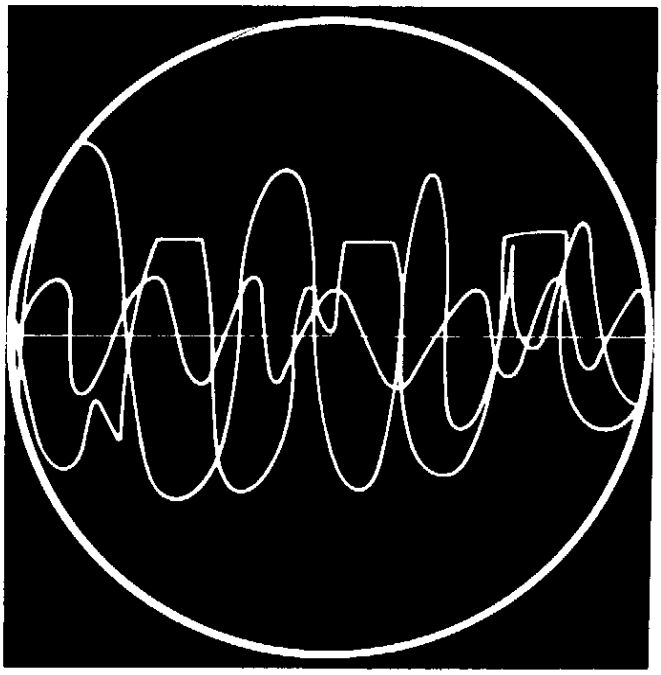


Fig. 8-3. Drawing of an actual scope pattern of a defective amplifier.

trouble; there in the background were several waveforms that were very obviously clipped (flat topped). So, just for luck, (and as a starting point, for I had already replaced several other parts with no results) I changed all of the coupling capacitors, using high-voltage types carefully checked for zero leakage before installation. This cured the complaint.

The distorted waveforms could probably have been spotted by making individual tests at many frequencies, but it was not necessary to go to such lengths. To find a stage that is causing distortion, be sure that your signal generator isn't set for too high an output. This will cause clipping (flat-topping) and severe distortion of the signal from overloading the amplifier.

The average audio signal generator can put out several volts of signal; even a high-output phonograph cartridge, used with a frequency test record, can do the same thing, so, make sure that you are not overloading the input. A voltage divider set up like that shown in Fig. 8-4 will help out. By using a pair of resistors, one 50,000 and one 950,000 ohms, you can get a 50-millivolt output. This is a good average input from a guitar pickup and should not cause overloading. To make sure, test with the scope at the plate of the first stage—the preamplifier tube. If there is any clipping due to too much input signal, it will probably show up there. For the final test, plug in the guitar itself and have the owner play a few chords on it while you watch the scope screen. To get best results in this test, always use a low-capacitance probe on the scope input. This will give the lowest loading on the high-impedance circuits you are working with.

You can also make stage-by-stage gain checks with the scope when troubleshooting weak amplifiers. Feed in the signal at the input. Set the signal-generator output for a clean sine wave. Now, put the scope probe on the grid of the preamp tube. Set the vertical gain of the scope so that the signal takes up a certain number of squares on the graticule (the calibrated screen on the scope). It doesn't make any difference how many as long as you remember. The best way is to make the signal cover a small number of small squares—say 5. Now move the probe to the plate. If this stage has a gain of 10, your pattern will be 10 times as high—50 small squares.

Many scopes have calibrated step attenuators. You can start by setting the attenuator to X1 for the first measurement. If you move it to X10 on the second and get a pattern of the same height, then this stage has a voltage gain of 10. Stage gain varies with tube types, voltage, and several other things. The preamp stages usually have very high gain, somewhere up around 15 to 25, while following amplifier stages may run between 10 and 15 as an average. As a rule, if a stage has low gain, you will be able to spot it even if you do not have the exact gain figures for that particular amplifier. If you get a gain of 10 to 15, that's probably pretty good. The tube manual will often give you a figure in the "typical characteristics" charts that you can use for a given tube.

Fig. 8-5 shows waveforms and stage gains for an imaginary amplifier. The signal always has the same shape, but the amplitude (height) increases. Even small amplifiers can have amazingly large amounts of actual voltage gain. When you remember that some amplifiers begin with a signal of only about 0.050 volt and wind up with perhaps as much as 50 volts, you can see that an overall voltage amplification of 1000 times is not unusual.

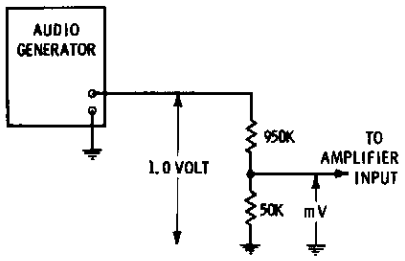


Fig. 8-4. Voltage divider to reduce generator output.

OSCILLATION, HUM, AND MOTORBOATING

Now and then you will find an amplifier that is oscillating. This means that the amplifier has some kind of internal feedback (the cause of all oscillation). There are several different kinds:

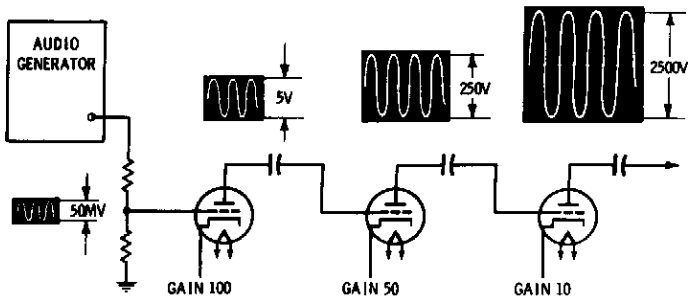


Fig. 8-5. Possible waveform values and stage gains.

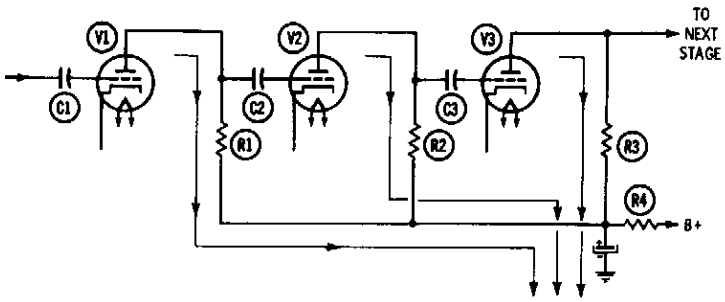


Fig. 8-6. Normal signal paths to ground.

1. Low-frequency oscillation is usually accompanied by a fairly bad hum. It is called motorboating from the "plup-plup-plup" sound it makes, something like an old motorboat (not a high-speed outboard).
2. High-frequency oscillation can sometimes be so high in pitch that the human ear cannot hear it —up around 20,000 or 25,000 Hz. It is also called ultrasonic oscillation. You cannot hear the oscillation itself, but you can hear the effects. It will cause the amplifier to have a very bad distortion.

Feedback

All oscillation is caused by a feedback. Amplifier circuits have many common connections such as the plate voltage supply circuit shown in Fig. 8-6. Only the plate circuit and grid circuit is shown, for that is all that is necessary. When there is a common plate supply circuit like this, it must be very well bypassed. A big electrolytic capacitor is put across the power supply from the B+ line to chassis or ground.

What does this do? In the plate circuits of all amplifier tubes there is a signal current flowing. It is taken off at the plate and fed to the grid of the following stage through the coupling capacitors (C1, C2, and C3). However, the rest of the current flows down through the plate resistors (R1, R2, and R3) and back to the B+ supply; it has to in order to make a complete circuit. Actually the signal is of no further value as soon as it leaves the plate of the tube; it must get to ground without creating any problems. The signal is alternating current, or to be more correct, it is a pulsating dc, like the plate current in all tubes. For convenience, the current is treated as if there were both ac and dc in the same circuit.

To get rid of the ac component, a big capacitor is connected from the B+ line to ground. This has a very low resistance to ac, so the B+ is at ac ground potential. There should never be any ac components on B+ lines. You can see from Fig. 8-6 that the signal currents flow down the load resistors and then through the low resistance of the capacitor to ground where they are lost. What happens if the capacitor opens up or develops a very high resistance (high power factor)?

This is different. Instead of any easy path to ground, the signal now has a very high-resistance path to ground if any at all. As you can see in Fig. 8-7, under these conditions the signal currents go everywhere. Instead of being dissipated harmlessly in the chassis, they can flow back up into other circuits. For example, the signal from tube V3 can get back into the plate circuit of tube V2, where it is promptly transferred through coupling capacitor C3 back to the grid of tube V3. The phase shifts in this feedback path are complicated, but it suffices to say that somewhere in there the signal manages to get back to a grid in exactly the right phase to cause in-phase regenerative feedback. The stage then goes into violent oscillation.

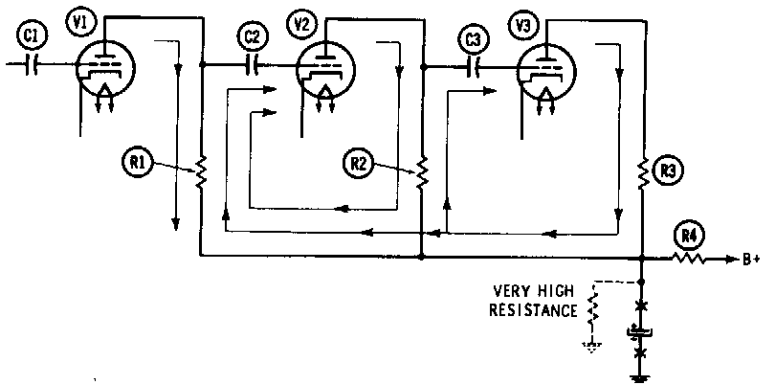


Fig. 8-7. Signal paths when bypass capacitor opens.

The scope is the best "weapon" for checking on this. Touch the scope probe to each of the dc power supply connections. You should never see anything but a nice "straight dc line." The presence of any signal on dc power supply lines shows that this circuit definitely does not have the absolute zero impedance that it must have if the amplifier is to work without feedback.

If one unit in a multiple-section electrolytic has gone bad, always be sure to replace the whole thing. The conditions inside the can which caused this one to fail will cause trouble in the others, in a very short time.

HEAT-SENSITIVE RESISTORS

A common trouble is the amplifier that "sounds all right when I first turn it on, but sounds awful after it works for a while," or "gets weak as it gets hot." This is some kind of *thermal* trouble; it is caused by some part in the amplifier getting hot and changing in value. The most common thermal troubles are resistors, although now and then a capacitor will do the same thing. A common example of this is the amplifier that won't work while in the cabinet, but when taken out on the bench for service, works for hours. This is because the amplifier chassis is better ventilated out in the open and stays cooler.

To find such troubles quickly, apply heat. One trick is to cover the amplifier chassis with a cardboard box, cutting off all ventilation (with it out of the regular cabinet, of course) and letting it run until the trouble shows up. Then take the box off very quickly and make tests of voltages, stage gains, etc., until you find the offending stage.

Once the stage is located, you can apply heat to individual parts by holding the tip of a soldering iron on them. You can tell very rapidly whether a given part is causing trouble. If any doubt remains on a resistor for example, take it completely out and hook an ohmmeter across it. Note the resistance reading and then heat it up, If the resistance changes more than about 5%, it is a good idea to replace it. Several resistors in the same stage, or the same amplifier, may be changing in value, so don't stop when you find the first one.

Some resistors will go up in value—most of them do, in fact. However, now and then you will find one that goes down. This makes no difference; if it changes in value at all, it is definitely bad and should be replaced.

Tubes will sometimes short out. When they do, a very heavy current is drawn through resistors in their circuits. This may overload and overheat resistors to such an extent that they will become thermals. Look for signs of overheating and charring, or a bad discoloration of the color-code paint. A good color to check is red; if the resistor has been overheated, the red stripe will turn a brownish-grey.

NOISY CONTROLS

Guitar amplifiers use standard carbon-element variable resistors for volume and tone controls. After a certain length of time, these controls get very noisy. If they are not worn too badly, they can be repaired by spraying contact cleaner into the body of the control. This washes away dirt and dust and cleans the sliding contact that is responsible for most of the noise. The standard test is to turn the amplifier on, turn the control rapidly up and down, and listen to the speaker. If the control is still noisy, you will hear it. In this case, replace it.

Worn controls must be replaced. The most common control used in these circuits is a standard audio taper of whatever resistance is needed. The 1-megohm control is often used, but you will find everything from 0.5 megohm to 2.5 megohms in use. These are not too critical; you can replace a 0.5 megohm with a 1 megohm if you have to, and there will not be a lot of difference in the performance. Exact duplicate replacements are best, of course.

FOOT-OPERATED CONTROLS

Because the guitarist's hands are usually pretty full, some instruments have foot-operated volume controls like that shown in Fig. 8-8. This is a standard volume control mounted in the foot-pedal assembly so an up or down movement of the foot raises or lowers the volume. It is connected into the amplifier circuits through a shielded cable and plug. These are usually wired in such a manner that the panel volume control is disconnected automatically when the foot control is plugged in.

In some a rack and pinion gear arrangement is used to move the control. Others have a cable-drive arrangement that does the same thing by means of

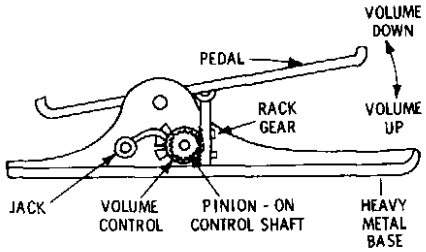


Fig. 8-8. Foot-operated volume control.

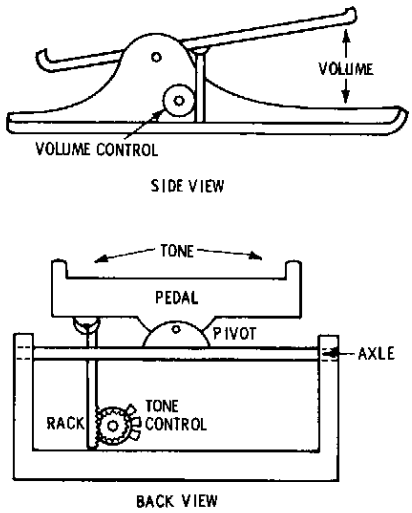


Fig. 8-9. Foot-operated tone and volume control mechanism.

winding a cable around the volume-control shaft. Slack is taken up by a spring.

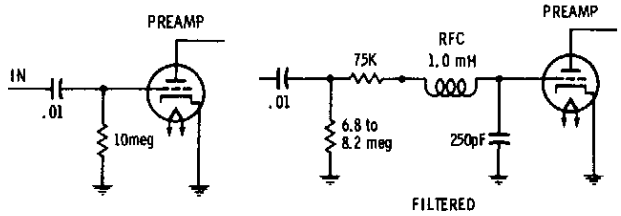
In a more elaborate version, straight up and down movement of the foot controls the volume, while rocking the foot from side to side controls the tone. A typical unit is shown in Fig. 8-9. The same basic hookup is used here to get the control action; there is just more of it. In one other application of the foot control, a simple on-off switch operates the vibrato on amplifiers equipped with this feature. Tremolo and reverberation circuits are often fitted with foot-operated switches too.

RADIO-FREQUENCY INTERFERENCE IN GUITAR AMPLIFIERS

As in all other kinds of electronics work, you will find the odd and unusual cases that will drive you crazy! Here is one of them that the author encountered. A string band, using one very large and one medium-sized amplifier, got along fine until they made a radio broadcast from the station itself. In the studio all of the instruments sounded so very peculiar that they finally had to turn off the amplifiers. This, to their surprise, cured the troubles.

The problem was traced to radio-frequency (rf) pickup in the input of the guitar amplifiers. Since studio and transmitter were in the same building, there was a very strong rf field all around them. The transmitter signal was being detected by the grids of the amplifier input stage. This generated a very high grid-leak bias (high negative voltage) and drove the input stages nearly to cutoff. Naturally, this caused a very severe distortion.

The cure was simple. Since the trouble was due to the presence of rf on the grids, a very small bypass capacitor was connected directly from grid to ground at each tube socket. Such a capacitor has a very low impedance at radio frequencies, so it makes a short circuit to ground for them. However, its impedance at audio frequencies is very high, so it doesn't affect the guitar tones. Fig. 8-10 shows how this is done. If



(A) Original circuit. *(B) Modified circuit.*

Fig. 8-10. Eliminating rf interference.

the capacitor alone does not entirely clear up this kind of interference, the small rf choke shown can be added in series with the grid.

MICROPHONICS

Microphonics is a word that needs more explanation. Previously it has been said that a contact mike can act as a microphone, picking up extraneous sounds in addition to string vibrations. Trouble very much like this can develop if one of the tubes in the front end (input stagés) becomes microphonic—translation, it acts as a microphone. Sound vibrations in the air can cause some of the tube elements to vibrate; this affects the electrical signals passing through it. The general result is a loud BONG when the amplifier chassis is touched or jarred. In bad cases tubes can even cause acoustic feedback, just like putting a microphone too close to a speaker. When the volume is turned up, the amplifier will howl dismally.

There is only one known cure for this—replace the tube. Some early efforts used special rubber-mounted sockets and fiber tube covers to damp out the sound vibrations, but these were pretty unsuccessful. The best cure is the use of specially designed nonmicrophonic tube types, like the 5879 shown in the microphone input circuit of Fig. 2-17. These are built with all elements rigidly held in place so they cannot vibrate when sound waves strike them. This construction keeps the tubes from becoming microphonic.

Transistors are very seldom microphonic because of their construction. However, nothing is impossible in electronics, so you may find a microphonic transistor before you finish reading this book. If you do, the same remedy applies—replace it. Most silicon transistors are comparatively noise-free and so far have given absolutely no trouble with microphonics or other noise effects.

INTERMITTENT AMPLIFIERS

The most infuriating complaint on an amplifier, or on any kind of electronic gear is an intermittent—one that works beautifully and suddenly quits. Then, in the standard intermittent, it starts working again just as if nothing had happened. Usually this happens just as soon as you get it out of the box and start looking for the cause of the trouble. You can hammer on it and do anything you want with it, and it plays on, just like new.

There are ways of dealing with these things. Intermittent operation means one thing—there is a loose connection somewhere. If the amplifier is playing and suddenly stops, only to start again in a moment, something is breaking the signal path. A tube is going dead, a coupling capacitor is opening up, or a resistor is opening and closing.

There are two main kinds of intermittents, physical and electrical. The physical type can be jarred to make it cut in and out. Something in there is mechanically loose—a bad solder joint, broken wire, an intermittent coupling capacitor, a dirty tube socket, etc. The electrical type can be hammered on with no effect; the amplifier simply cuts out when it gets ready to. The latter are the most annoying intermittents, of course.

If you find a physical intermittent, take the amplifier out of the cabinet, set it up on the bench, feed a continuous signal through it so that you can tell when it cuts out, and then tap every part in it. Right now you have no ideas at all as to where this thing is located; it could actually be caused by almost any part in the whole amplifier.

Here is another place to use the process of elimination. Start at the power output tube socket, and tap all of the parts in the signal path—coupling capacitors, resistors, tube sockets, tubes, etc. Use something like a pencil eraser or an insulated tool of any kind. If you get close to the cause of the trouble, you will notice that you hear a pop every time you hit a certain part. This is very apt to be the one you are hunting.

Don't hammer on the whole chassis; this does no good at all. What you must do is tap or jar certain parts without moving the rest of the amplifier in an effort to pin down the trouble to a small area. If you jar the whole chassis naturally you are going to get a response. Take it easy, and hammer gently and selectively.

Dirty or old tube sockets are a common cause of physical intermittents. Put your finger on the top of each tube, and move it around in the socket. If you hear a popping or scratching noise, the tube pins and the socket contacts are dirty. Take the tube out, spray contact cleaner into the socket, and straighten out the pins. Put the tube back in. Push it up and down several times in the socket; this scrapes the corrosion off tube-socket contacts. Now tap it again, and see if the noise has stopped. If it has not, substitute a new tube and try again. The original noise may have been inside the tube itself (a common trouble not too long ago, but not so common now, with improvements in the internal construction of vacuum tubes). Don't replace the tube first in this case; clean up first. You may put in a new tube with clean pins, and throw away a perfectly good tube with dirty pins.

If the new tube doesn't stop the noise, then it must be coming from one of the parts connected to this particular tube. Turn the amplifier over and give these parts a good working over with your hammering tool. Look closely at every solder joint around the socket; some of them may be bad. In printed-circuit amplifiers it is often helpful simply to resolder all connections around that socket; melt each one, apply just a tiny bit of fresh solder, and let it cool. In the early printed-circuit boards this kind of trouble was common, but here again material improvement has stopped a lot of it.

The most annoying type is the electrical intermittent. No amount of hammering will affect it; it just suddenly stops working when it gets good and ready! Of course if it stays out, it is easy to locate the trouble by signal-tracing—but it usually doesn't. Many will cut out, but will come on the moment a test probe is placed anywhere on the circuit.

There are ways of dealing with these, of course. One good way is to connect indicators of some kind to several points in the circuit. For example hook the scope to the grid of an output tube, a vtvm on "ac volts" to the plate of an amplifier tube, and a dc voltmeter to some point along the B+ supply lines. Now, turn the unit on and wait until it cuts out. By checking the reading on each of the indicating instruments, you can get some idea of where the circuit is opening. In this example, if the scope shows that the signal disappeared from the grid of an output tube, but the ac vtvm shows no change in its reading, then you have the defect pinned down to somewhere between those two points. Move the scope one stage closer to where the vtvm is connected, and try again. Eventually you will be able to close in on the thing and find out exactly which part is giving trouble.

Many intermittents are thermal—they show up after the amplifier has been turned on long enough to get thoroughly warmed up. In these cases some part expands physically due to heat and breaks the circuit.

For example, a paper capacitor that has been installed with too much tension on the connecting leads will open with heat; when the capacitor expands, the end of the capacitor is pulled loose and it becomes open, stopping the signal.

To catch a thermal intermittent, put the amplifier on the bench and cover it up with a cardboard box, blanket, or anything that will hold the heat in. Let it get hot and cut out, and then you will be able to find the bad component easily. Try applying heat to suspected parts of any kind with the tip of a soldering iron; this will often cause intermittents to show up.

Some units operate in reverse; they won't work at all until they are thoroughly warmed up. Then they come on very suddenly, and refuse to cut out at all until they are cooled off again. There is a way to deal with this, too. You can get coolant fluid in spray cans at electronic parts houses. This can be sprayed on suspected parts to cool them off, possibly making the trouble show up.

The easiest way, of course, is to cool the amplifier off, and check it by signal tracing while the part is defective. However, this can have its drawbacks. Many chassis will not cool off enough to cut out for a long time after they have started to work. One exasperated technician put an amplifier like this into his deep freeze and really cooled it off. He found the trouble very quickly, too, I might add.

SUMMARY

Servicing guitar amplifiers is not difficult if you use the right methods, and, above all, if you know how the circuits work. A logical method of eliminating first one possible cause and then the next will lead you to the real cause of trouble in the shortest possible time.